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THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

Producibility Cost Reductions Through Alternative Materials and Processes

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

in cooperation with
Newport News Shipbuilding

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PRODUCIBILITY COST REDUCTIONS THROUGH ALTERNATIVE MATERIALS AND PROCESSES

Submitted to

Newport News Shipbuilding
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EXECUTIVE SUMMARY

This report describes research into the use of alternative materials and processes to reduce material and labor costs while also looking at the influence of these choices on the life cycle costs of the vessel. Some of the traditional methods and materials used in shipbuilding are questioned, and alternatives are evaluated. The research, sponsored by the National Shipbuilding Research Program (NSRP) through the SP-8, Industrial Engineering Panel of the Society of Naval Architects and Marine Engineers (SNAME) Ship Production Committee, looks specifically at increased use of fiberglass and plastic pipe, adhesives, and flexible and rubber hose as areas where cost and producibility gains may be found. Cost comparisons between traditional and alternative methods are presented as well as applicability to regulatory and classification society requirements.

This research was conducted by the Marine Systems Division (MSD) of the University of Michigan Transportation Institute (UMTRI), the Shipyards Division of Avondale Industries, and Damilic Corporation, to investigate and test the use of alternative materials and processes to reduce the life cycle cost of ships. For each of the subject focus areas of fiberglass and plastic pipe, adhesives, and flexible and rubber hose, traditional methods and materials are questioned, and alternatives are evaluated. The regulatory and classification policies on fiberglass and plastic pipe, and on flexible and rubber hose, became fairly well established between the time research was envisioned and the time it actually began. The technology in these two areas was already established, so that part of the research centered on a cost benefit analysis

The adhesives area seemed to be the most promising in the area of labor savings and the least addressed by specific regulatory and classification policies. Adhesives bonding is an alternate means for mechanical fastening and welding of nonstructural and noncritical shipboard items. The research then centered on the choice of adhesives that offered the best combination of holding power and ease of application without some of the negative attributes of volatile compounds (that would require additional ventilation, worker protection, or both) or excess preparation. Shock testing was also conducted. Practical regulatory concerns for the performance of the adhesives in a fire seemed to dominate consideration of their application.

All three alternative areas offer reduced material cost and labor for installation compared to traditional methods. Life cycle cost projections are similarly promising.

PRODUCIBILITY COST REDUCTIONS THROUGH ALTERNATIVE MATERIALS AND PROCESSES

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Introduction

The competitive nature of shipbuilding requires that successful builders and ship owners use the most cost effective means to construct their ships considering the full life cycle. This report describes research into the use of alternative materials and processes to reduce material and labor costs while also looking at the influence of these choices on the life cycle costs of a ship. Some of the traditional methods and materials used in shipbuilding are questioned and alternatives are evaluated. The research, backed by the National Shipbuilding Research Program (NSRP) through the SP-8, Industrial Engineering Panel of the Society of Naval Architects and Marine Engineers (SNAME) Ship Production Committee, looks specifically at increased use of fiberglass and plastic pipe, adhesives, and rubber hose as areas where cost and producibility gains may be found. Cost comparisons between traditional and alternative methods are presented as well as applicability to regulatory and classification society requirements.

This research was conducted by the research team of the Marine Systems Division (MSD) of the University of Michigan Transportation Institute UMTRI, the Shipyards Division of Avondale Industries, and Damilic Corporation to investigate and test the use of alternative materials and processes to reduce the life cycle cost of ships. For each of the subject focus areas of fiberglass and plastic pipe, adhesives, and rubber hose, traditional methods and materials were questioned and alternatives were evaluated. The research task arrangement was as follows.

- Task 1. Identify Areas of Potential Use.
- Task 2. Identify Function Specifications.
- Task 3. Identify Potential Candidates.
- Task 4. Test and Evaluate Candidates .
- Task 5. Seek Regulatory Acceptance.

The first four tasks have been reported in previous milestone reports which are attached as appendices to this report. Also in Appendix C is the technical paper presented at the 1997 Ship Production Symposium.

The research team established that the most likely areas for saving significant time and cost. were adhesives, flexible hose and fiberglass pipe. A preliminary list of items in each of the interest areas was developed and presented to the SP-8 Panel as milestone reports on the first three tasks. The technology on fiberglass and plastic pipe, and on flexible and rubber hose, was fairly well established as was regulatory acceptance by the time research began.

The focus of the research was primarily on applications to commercial vessels, followed in precedence by naval auxiliaries and then combatants. The adhesives area seemed to be the most promising in the area of labor savings. The research centered on the choice of adhesives that offered the best combination of holding power and ease of application without some of the negative attributes of volatile compounds (that would require additional ventilation, worker protection, or both) or excess preparation.

Some technical aspects of the research were overtaken by events as work progressed. The American Bureau of Shipping (ABS) published guidelines for the use of rubber hose and plastic pipe for a number of locations and applications. The International Maritime Organization (IMO) published similar rules. Discussions with the U.S. Coast Guard revealed some reservations about extensive use of adhesives as a safety issue. The Coast Guard was concerned that the possibility of falling debris during a fire could either block an escape passageway or hinder a fire fighting party. Applications for minor parts were not an issue.

The cost benefit analyses detailed in Milestone 4 (Appendix E) show that all three technologies have economic drivers to encourage their use. Specific applications of alternatives require approval from the authority having jurisdiction just like any other item on a ship.

Background and Technical Approach

The SP-8 Industrial Engineering Panel of SNAME's Ship Production Committee perceived the need for a number of alternative production materials and processes, in areas that consume a large number of labor hours and time in shipbuilding. Thus, the abstract for this project was developed. The Executive Control Board endorsed the Panel's decision by approving the 8-95-1 project as the highest priority of the industrial engineering projects for FY 95.

The team put together by UMTRI/MSD to execute this project was enthusiastic about the potential to reduce cost and time in shipbuilding by the alternative materials and processes developed through this project. Use of adhesives, flexible hose, and PVC/GRP pipe were examined for application to both domestic and international products. Producibility gains were expected to carry over to the repair side of the industry also.

Applying the ship production and engineering background of UMTRI/MSD and Avondale, the team established the most likely areas where adhesives, flexible hose and PVC/GRP pipe could be used to save significant time and cost in commercial and naval ships. Avondale prepared a preliminary list of items in each of the interest areas that were used as a starting point for the research as detailed in the first milestone report in Appendix A.

Dr. George Ritter at the Naval Joining Center (NJC) at the Edison Welding Institute (EWI) was consulted to provide an external check on our findings. His letters are in Appendix F. Both system performance and regulatory control specifications that govern the use of these alternatives for shipboard applications were studied to consider the most likely candidates. In parallel with further engineering investigations into applications, preliminary determinations for meeting relevant military and/or commercial safety and performance requirements were sought.

Out of the study above, potential candidates for further testing in each area were chosen with the concurrence of the NJC and the SP-8 Panel's Technical Oversight Committee (TOC), then carried through the remainder of the research.

The items or technologies selected were first evaluated based on manufacturer's data and an engineering analysis. Those items passing this evaluation were physically tested, first in a simplified manner in a lab (but in realistic situations), then in a real world production environment at Avondale. Measures of cost and productivity were evaluated and compared to existing cost data to establish the actual benefit to both the initial cost of a ship and to the life cycle costs.

The detailed plan for performing the project was covered by the following specific tasks which follow the format of the RFP.

Task 1. Identify Areas of Potential Use.

Task 2. Identify Function Specifications.

Task 3. Identify Potential Candidates.

Task 4. Test and Evaluate Candidates .

Task 5. Seek Regulatory Acceptance.

These tasks are more fully explained below.

Task 1. Identify Areas of Potential Use. Avondale and UMTRI/MSD identified areas of potential use. The research team applied its collective ship production and engineering background to establish a preliminary list of candidate areas where adhesives, flexible hose and PVC/GRP pipe could likely be used to save significant time and cost in commercial and naval ships. The primary focus was on commercial applications, with due consideration for the needs of military and auxiliary ships. The results of this task were reported in the first milestone report (Appendix A).

Task 2. Identify Function Specifications. UMTRI/MSD and Avondale identified the commercial, MilSpec and ShipSpec performance requirements that apply to each of the candidate items from Task 1. The other team members were consulted to ensure that all applicable specifications were identified. These specifications were studied to consider the most likely candidates for further testing and evaluation. The results of this task were also reported in the first milestone report (Appendix A).

Task 3. Identify Potential Candidates. Those materials and processes that were subjected to the Task 1 and 2 evaluations, along with their attributes and regulatory requirements, were evaluated further and, with the concurrence of the SP-8 TOC were moved into the Task 4 physical testing phase. The results of this task were reported in the second milestone report (Appendix B).

Task 4. Test and Evaluate Candidates. The materials and processes evaluated in the previous tasks were evaluated based on the expectation that they would perform in the testing phase. This task was broken down into the three process areas of adhesives, flexible hose and PVC/GRP pipe. Each process area includes a basic engineering analysis, a laboratory or simplified practical test component, and an on site evaluation at Avondale. Details of the tests were reported in the third and fourth milestone reports (Appendix D and E).

Task 4-I. Adhesives

The Damilic Corporation led this process area and was involved in the tasks leading up to it. An ideal program of testing all candidates to ensure absolute reliability for shipboard use was beyond the scope and budget of this program. A number of specimens were tested in the lab available to Damilic to verify theoretical adhesive values or those claimed by various manufacturers. Avondale provided small steel specimens with various coatings, such as primer and finish paint, to simulate applications of adhesives in various stages of production. The procedures required to prepare the surface were documented. The physical strength of the bonded surface was tested in lap shear, tensile, and peel modes to simulate loads in service. We were not be able to test all candidates in a statistically valid exhaustive test series, but were able to validate initial engineering calculations for their required performance.

Damilic also checked the testing of the selected items at Avondale in a production environment. Avondale measured the labor required for the adhesive method and compared it to the previous method of application. A full labor and purchase cost benefit analysis was performed for each tested arrangement. An instrumented destructive physical test was performed via shock testing to validate the lab findings, and the results were tabulated in the test reports.

Testing at Avondale on the zinc anode installation with adhesives had not been completed in time to make the fourth milestone report (Appendix E) and is reported here. As described in the other appendices, installation of zinc anodes in ballast tanks was considered a likely area where adhesives could be used with maximum cost saving but minimal safety concerns. Table I shows the tasks and time involved to install individual zincs in various ballast tanks.

Table I. Zinc Anode Installation

Step	**Welded** Method – New Installation	Labor Hours
1.	Gather tools for grinding, prep, and spot welding at installation area.*	1.0
2.	Secure hot work permit for grinding and welding at installation area.	1.0
3.	Grind and clean area of mounting stud installation.*	0.5
4.	Locate and mark area for installation of welded studs.*	0.5
5.	Weld studs in place.*	0.5
6.	Install zinc anode onto studs. *	0.25
7.	Install nuts onto studs to fasten zinc anodes in place. *	0.25
8.	Return tools and equipment required for installation.	0.5
	Total labor hours for welded anode installation	**4.5**
	Adhesive Method – New Installation	Labor Hours
1.	Gather tools for grinding and preparing at the installation area.	0.5
2.	Secure hot work permit for grinding and at installation area.	1.0
3.	Grind or clean area of mounting stud installation. *	0.5
4.	Install adhesive and install anode.*	0.25
5.	Return tools and equipment required for installation.	0.5
	Total labor hours for adhesive anode installation	**2.75**

*repeatable tasks

Avondale is in the middle of a production run on 7 Bob Hope class sealift auxiliaries, each of which has approximately 3200 zinc anodes. Table II is the estimate of the savings from the repeatable tasks in labor hours for zinc installation on these ships. Hot work permits are used by both methods, and so are not considered in this comparison. Dragging around the cables, guns and power sources for stud welding is considered to take 0.5 hour extra per welded anode. This is a conservative estimate because a worker using adhesives incurs the non-repeatable expenses less often.

Table II. Zinc Installation Labor Cost Savings

	Welded	Adhesively Bonded
Repeatable labor hours for each installation	2.5	.75
Additional labor cost per item @ $30/hr burdened labor rate	$75	$22.50
Labor cost per ship with 3200 Zincs	$240,000	$72,000
Labor cost for 7 ships	$1,680,000	$504,000
Potential Savings		$1,176,000

The potential for nearly $1.2 million in labor cost savings for just one application of adhesives bonding in place of welding is significant.

Tasks 4-II and III.
Flexible Pipe and Rubber or Composite Hose / PVC/GRP Pipe

The team evaluated a number of flexible hose and pipe types, mostly through an economic cost benefit analysis. The technical aspects of using these materials were detailed in new IMO guidelines published as IMO Resolution A.753(18) developed during the progress of the research. See http://www.imo.org for ordering information. Revisions to the ABS Rules incorporate the IMO standards. The economic analyses showed in a variety of areas that both flexible hose and PVC and GRP pipe are viable alternatives in many systems to traditional steel pipe construction. Candidate materials systems have been tested and are type approved by ABS and other classification societies.

Avondale measured the labor and material required for installing the hose or flexible pipe pieces, and PVC and GRP pipe and tube, and compared those figures to traditional materials and methods of application. The detailed breakdown of this analysis is in the appendix. Full labor and purchase cost benefit analyses are reported. Table I is the summary of the findings showing the initial installation advantages of the composite and plastic materials. Not included as a detailed line item is the life cycle cost advantage of the plastics compared to the corrosion of the steel pipe.

Table III. Summary Cost Comparison

	LABOR	MATERIAL	TOTAL
STEEL	$32,165	$6,495	$38,660
COPPER NICKEL	$32,165	$13,471	$45,636
GRP	$23,115	$19,634	$42,749
PVC	$12,965	$4,870	$17,835

Task 5. Seek Regulatory Acceptance. As stated previously, acceptance of the alternatives was eventually covered by international classification society specifications and IMO guidelines specified in the fourth milestone report. Acceptance of the adhesives is based on specific item approvals. Reservations by the Coast Guard regarding performance in fire, and the possibility of blocking escape routes, or hindering a fire party, must be addressed for each application.

Conclusions

All three alternative areas offer reduced material cost and labor for installation compared to traditional methods. Life cycle cost projections are similarly promising. Each of the subject focus areas of fiberglass and plastic pipe, adhesives, and rubber hose showed the potential to save considerable amount of material, labor, and life cycle repair related costs in the life of a ship.

APPENDIX A

Milestone 1 Report

PRODUCIBILITY COST REDUCTIONS THROUGH ALTERNATIVE MATERIALS AND PROCESSES

Milestone 1 Report

Submitted to

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Newport News Shipbuilding
4101 Washington Avenue
Newport News, Virginia 23607

by

The University of Michigan
Transportation Research Institute

with

Avondale Industries, Inc.

February 19, 1997

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Producibility Cost Reductions
Through Alternative Materials and Processes

The University of Michigan Transportation Research Institute, Marine Systems Division (UMTRI-MSD), along with Avondale Industries, Inc., Shipyards Division (Avondale), submits this Milestone 1 Report to Newport News Shipbuilding (NNS) as agreed in the milestone payment schedule letter of January 11, 1996. This report is the "Area of Use and Function Report" and covers completion of

Task 1. Identify Areas of Potential Use, and
Task 2. Identify Function Specifications.

It establishes the most likely areas where adhesives, flexible hose and PVC/GRP pipe can be used, in commercial and naval ships, to save significant time and cost. A preliminary list of items in each of the interest areas was presented in the proposal and has been expanded through shipyard visits and discussions in the work of the project team. Further analysis continues on the preliminary items produced in the lists in this report. Our focus is primarily on applications to commercial vessels, followed by naval auxiliaries and combatants.

The resources of the Center of Excellence for Composites Manufacturing Technology (CECMT) and the Naval Joining Center (NJC) will be consulted after Panel acceptance of this report to assist in determining specific items to be carried into further phases of testing. Regulatory, naval, and class society acceptance are being considered or pursued as progress continues in parallel with further engineering investigations into applications. These are preliminary determinations for meeting relevant requirements, as specific approvals are only given for specific applications.

Adhesives

The adhesives area seems to be the most promising in the area of labor savings. Our research is centering on the choice of adhesives that offer the best combination of holding power and ease of application without negative attributes of volatile compounds (that would require additional ventilation, worker protection, or both) or excess preparation.

Adhesives bonding is an alternate means for mechanical fastening and welding minor shipboard items. Adhesives also provide a means for easy on site repair or modification to fixtures. Potential shipboard applications for adhesives include clocks, clinometers, thermostats, and miscellaneous outfitting stowage attachment of small pipe hangers (especially for small diameter pipe and gauge tubing, label plates, equipment mounting brackets, and curtain plates). (See Table I. The full page tables are listed at the end of the document.) These attachments can be expected to be exposed to temperatures between 0 and 120^{o} F and a relative humidity of 90% or more, during both installation and service life. Adhesives can be formulated to be either thermally conducting, electrically insulating or visa versa.

Literally thousands of structural adhesives are available commercially. Table II describes the five most widely used chemically reactive structural adhesives, epoxies, urethanes, acrylics, cyanoacrylates, and anaerobics. Candidate adhesives for the project were selected from a broad review of commercially available adhesives because of their general utility (Table III). These adhesives have been selected because they

- can be cured at ambient temperatures with minimal additional heat required;
- pose minimal exposure hazard to workers; and
- can be easily applied with a trowel, caulking gun, syringe, or gun dispenser.

In addition, the adhesives listed posses a minimum tensile shear strength of 1,000 psi and a minimum heat deflection temperature of 110 ^{o} F. Most of the adhesives listed will perform well at temperatures up to 200 ^{o} F (in the absence of high humidity) and exhibit tensile shear strengths in excess of 2000 psi (against primed steel or aluminum substrates). Specialized adhesives can develop up to 10,000 psi shear strength. Ongoing work involves measuring claimed adhesion against steel samples sent from the shipyard in various stages of paint preparation.

Flexible Hose

The use of flexible hose in commercial and military shipbuilding appears to have been approved by classification societies and regulatory bodies well beyond its observed usage in new construction. With the advent of new materials, testing has been performed and approvals have been secured for the use of flexible hose in a number of areas. A general lack of awareness of the extent to which the use of flexible hose has been approved, coupled with the natural inclination of shipbuilders to retain the use of traditional shipbuilding practices and materials, has inhibited the widespread use of flexible hose to the extent allowable.

It seems evident that in-depth studies have not been performed on the use of flexible hose to the extent allowable under current approval. If studies have been performed, the results have not been widely disseminated. Table IV depicts the current areas of approval for various flexible hose applications.

In determining the suitability of flexible hose for a given application, hose assemblies are first classified as critical or noncritical depending on the system they are used in and the redundancy in that system. The level of criticality determines the replacement cycles for various hose assemblies and thereby contributes to determining the type of hose approved for use. In determining the level of criticality assigned to a given hose, the following attributes are considered and weighted as pertinent factors.

System. The system category is divided into five major sections, each reflecting a fluid type, except for drains, which are all inclusive.

- Gasses
- Water
- Sea water
- Drains
- Oil systems

Pressure Ratio is determined by dividing the rated working pressure of the hose by the system working pressure.

Impulse is defined as any pressure spike that momentarily raises the pressure in the hose.

Temperature is the working temperature range of a hose includes the lowest and the maximum temperature that the hose could be exposed to.

We are currently identifying and documenting those areas in which the use of flexible hose is acceptable according to classification societies and regulatory bodies, and comparing the potential use to actual existing standard shipyard practice. We will then analyze the potential labor savings and ancillary economies that could be recognized by fully adopting the use of flexible hose in all approved areas.

It is anticipated that the incorporation of flexible hose to the extent currently allowable in new ship construction would reduce manufacturing, modification, and repair costs as well as reduce vessel weight and lower long term maintenance and operation costs.

PVC/GRP Pipe

The use of fiberglass pipe on board commercial as well as military ships has proliferated substantially, although sporadically, over the past several years. While several recognized classification societies and regulatory bodies have approved the use of fiberglass pipe in designated areas, other areas have not been addressed or do not currently have widespread approval. A chart of current approvals is attached as Table V.

With the recent introduction of poly-siloxane modified phenolics in fiberglass pipe fabrication, a number of previously beneficial attributes of fiberglass pipe have been enhanced and a number of significant advances have been attained. At the same time, some heretofore negative characteristics have been mollified. Table VI below lists some of the positive and negative attributes of these base materials.

Table VI. Attributes of Phenolic Pipe

CONVENTIONAL	**PHENOLICS**
Positive Attributes	**Negative Attributes**
Excellent high temperature resistance	Poor adhesion for bonded joints
Low flame spread	Limited pressure performance due to low elongation and brittle nature
Corrosion resistance	Limited impact resistance
Low smoke and toxicity in fire	
Light weight	
Poly-Siloxane	**Modified Phenolics**
Positive Attributes	**Negative Attributes**
All the same plus	To be seen
Improved fire resistance	
Improved adhesion (160%)	
Improved elongation (30%)	
Improved impact resistance (40%)	

A substantial amount of testing has been performed to verify the enhanced physical characteristics as well as improved fire performance of poly-siloxane modified phenolics. Among these tests are the following.

- IMO fire endurance testing - level 3 - eight tests carried out in two sizes and four configurations. In accordance with ASTM F1173 -95.
- SINTEF jet fire.
- ASTM E-84 - standard test method for surface burning characteristics of building materials (tunnel test).
- Pittsburgh toxicity.
- ASTM E-162 - test method for surface flammability of materials using a radiant heat energy source.
- ASTM E-662 - test method for specific optical density of smoke generated by solid materials.
- ASTM D-635 - rate of burning and/or extent of burning of self supporting plastics in a horizontal position.
- ASTM E-1354 - test method for heat and visible smoke release rates for materials and products using an oxygen consumption calorimeter.
- Lap shear strength physical.
- Short term burst.
- Hoop stress.
- Impact resistance.
- Flexural.
- Modulus of elasticity.
- Chemical resistance.
- Weathering resistance.
- Steam resistance.
- Corrosion resistance.

Comparison To Metallic Piping Systems. Compared to metallic piping systems, fiberglass, composite or plastic piping has a number of advantages. The following list shows some of the detractors of metallic materials compared to plastic.

- Carbon Steel - Inherently corrosion prone - requires constant maintenance and frequent replacement; requires high level of installation and/or repair expertise.
- Copper Nickel - High initial material and installation cost; costly to repair or modify; requires high level of installation and/or repair expertise.

- Stainless Steel - High initial material and installation cost; costly to repair or modify; requires high level of installation and/or repair expertise.
- Fiberglass Pipe - Moderate initial installation cost; will not corrode; very low maintenance; low skill level required for installation, modification, or repair. Repairs can be accomplished without certified welders, welding machines or burning equipment.

Table VII below is a comparison of the installed costs of a typical 100 mm (4 in.) offshore fire protection piping system.

Table VII. Comparative Cost of a Fire Protection Piping System

Pipe System Material	Cost per Meter	Cost per Foot
Carbon Steel	$82	$25
Copper Nickel (CUNI)	$295	$90
Stainless Steel	$312	$95
Composite	$115	$35

The composite fire protection piping system, with intumescent coating, is capable of maintaining serviceability of the pipe for a minimum of three hours in a severe fire test. The life cycle advantages of the noncorroding composite pipe are expected to overcome the installed cost disadvantage.

With this type of performance available, the goal of the project is to promote the certification and approval of fiberglass pipe into areas currently not approved including

- cargo piping,
- fire system piping,
- bilge systems,
- freshwater cooling,
- sea water cooling, and
- similar critical areas.

We also plan to promote the acceptability of fiberglass pipe for use on military vessels as already approved by nonmilitary regulatory and classification societies.

The expanded incorporation of fiberglass pipe on both military and non-military vessels is expected to reduce manufacturing, modification, and repair costs as well as reduce vessel weights and lower long term maintenance and operation costs.

FUTURE WORK

Our future work is geared towards ascertaining which of the most promising candidates from the first two tasks will be tested on site at Avondale.

CECMT and NJC will review the list of candidates. Each process area includes a basic engineering analysis, a laboratory or simplified practical test component, and an onsite test at Avondale. The members of the project team have a working relationship with vendors of most of the products expected to reach this phase of the research, so we do not anticipate having to purchase many materials for evaluation. There is, however, a part of the budget reserved for purchases.

In parallel with further engineering investigations and testing, we will seek preliminary determinations for meeting the relevant military and/or commercial safety and performance requirements from the applicable agencies. As much as possible, these will be applied to ongoing construction programs at Avondale to provide relevance to real world shipbuilding programs. Inspectors are already on site at Avondale from the Navy, Coast Guard, and ABS to perform spot survey checks of the new applications tested for this project.

Table I. Candidates for Attachment by Adhesives

Bonded Items	Bond Area (sq. in.)	Comments
Curtain Plates	100-2000	Vertical placement, large surface area, good tack or green strength desired
Equipment Mounting Brackets	10-200	Vertical placement, high strength needed, long working time desired
Equipment Mounting Foundations	100-2000	Large volume application, strength and durability required
Insulation Mounting Clips	10-50	Adhesives would eliminate need to bring welding equipment on shipboard, long working time not necessary
Label Plates	10-200	Adhesives would eliminate need to bring welding equipment on shipboard, long working time not necessary
Pipe Hangers	10-50	Numerous areas on shipboard; adhesives would eliminate need to bring welding equipment on board, also easy on site repair, intermediate festering time desirable
Plumbing Fixtures	10-200	Numerous areas on shipboard; adhesives would eliminate need to bring welding equipment on board, also easy on-site repair
Thermal/Acoustical Insulation	50-1500	Adhesive would reduce the need to weld numerous studs also easy on site repair
Wire Hangers	10-50	Numerous areas on shipboard; adhesives would eliminate need to bring welding equipment on shipboard also easy on site repair
Zinc Anode	50-250	Eliminates the need to weld steel studs on shipboard in tight space

Table II. Chemical Adhesive Groups

Chemical Family	Advantages	Comments
Epoxy	high strength; good solvent resistance; good elevated temperature resistance; good gap filling capabilities; wide range of formulations	ambient cure is almost always a two component system, which requires either metering and premixing or dispensing equipment. Short pot life.
Polyurethane	flexible, tough; is used in adhesive sealant formulations	moisture sensitive; when purchased as a two component system, one component is unreacted isocyanate - a toxic chemical
Acrylics	good flexibility; good peel and shear strength will bond oily surfaces room temperature curable moderate cost	some are toxic and flammable (modified acrylics); more expensive than general purpose epoxies
Cyanoacrylates	one component; good adhesion to metal; minimal quantities required	instant cure limits fixturing time; low viscosity; good capillary action; more commonly known as super glue
Anaerobic	one component; long pot life; nontoxic	thread locking adhesive, brand names include Locktite

Table III. Preliminary Adhesives Selection

Adhesive Type	Brand Name	Material Form	Applicable Substrate	Application Method	Cure Conditions	Special Features
epoxy	DAPCO 3004	two component	metal, wood, concrete, plastic	extrusion, trowel	4 hrs	3,000 psi tensile strength
epoxy	Magnobond 6155	two component	plastic	trowel	7 days @ 70^{o}F	same as above
epoxy	Norcast 7285-1	one component	metals, plastics, etc.	trowel	3 hrs @ 250 ^{o}F	flame retardant
epoxy	Norcast 9310	two component	general purpose	casting resin		
epoxy	Epoxies, etc. 10-3020	two component	steel, wood	syringe	20 min @ 77^{o}F	
epoxy	Epoxies, etc. 10-3050	one component	steel	trowel	24 hr @ 77^{o}F	8,000 psi tensile strength
modified acrylate	Advanced Adhesives systems 4325	two component	primed steel/fiberglass	dispensing gun	24 hr @ 77^{o}F	3,500 psi tensile strength / high humidity
modified acrylate	Dymax 828	liquid, two part	primed steel	brush on, bead on	local pressure	3,000 psi tensile strength / 300 ^{o}F
epoxy	Armstrong A-12	liquid, two part	primed steel	brush on, bead on	local pressure	mil spec epoxy, 2900 psi 300^{o}F
methacrylate	Plexus MA-310	liquid, two part	steel/fiberglass		local pressure	250^{o}F/tough
epoxy	Masterbond EP76M	liquid, two part	steel/fiberglass	trowel	24 hrs @ 77^{o}F	300^{o}F
epoxy	Philadelphia Resins TA-30	two component	general purpose	trowel	24 hrs @ 77^{o}F * no festering	tile adhesive, non-sag/150^{o}F 3200 psi tensile strength
epoxy	Philadelphia Resins 6470	two component	structural resins	crushable, rollable	8 hrs @ 77^{o}F	water resistant 1,200 lap sheer steel/4,700 tensile strength 200^{o}F
cyanoacrylate	Pacer Technology M-100	100 cP	primed steel	roughening/ cleaning	instant 30 sec	poor moisture, brittle
cyanoacrylate	Pacer Technology HP-500	5000 cP	general	brush on	1 min	
cyanoacrylate	R-X	thick	general	gel, paste	2 min	

Table III. Preliminary Adhesives Selection, cont'd

Adhesive Type	Brand Name	Material Form	Applicable Substrate	Application Method	Cure Conditions	Special Features
epoxy	Gougeon Bros-Proset 175/275	two component	steel	caulk gun	8-24 hrs @ 77^{o}F	no post cure, 200^{o}F no load, 130^{o}F w/load
epoxy	Gougeon West System 105/205	two component	fiberglass, steel	hand mixed brush on	8-24 hrs @ 77^{o}F	no post cure, 200^{o}F no load, 130^{o}F w/load
polyester	ATC Chemical - Poly-Bond B41F	two component	fiberglass, steel	calibrated dispenser, thix paste	24 hrs @ 77^{o}F	tough, low shrinkage, used in hull to deck marine applications
polyester	ATC Chemical - Poly-Bond B39F	two component	fiberglass, steel	calibrated dispenser, thix paste	24 hrs @ 77^{o}F	tough, low shrinkage, used in hull to deck pumpable
urethane	Sika 241	one component	steel, fiberglass, etc.	gun dispenser	24 hrs @ 77^{o}F	semipermanent
urethane	Sika 292	one component	steel, fiberglass, etc.	gun dispenser	24 hrs @ 77^{o}F	sealant, good above or below water line
urethane	3M scotch- seal 5200	one component	steel, fiberglass, etc.	gun dispenser or trowel	24 @ 77^{o}F	comparable to Sika 241
acrylic/Ag/Ni	3M 9703	tape	alcohol wipe/ abrasion	even pressure 40 psi	72 hrs	conductive
acrylic - modified methylmeth-acrylate	Hernon MI React 730; Act 56	two component	unprimed steel/primed/ painted	syringe applied bead on	24 hrs @ 77 ^{o}F	visc 6000 cps, 1-2 min fix time, tensile strength 3 ksi/grit blast steel; -60F - 250 F; nonflammable
acrylic mod-ified methyl-methacrylate	Hernon MI React 761; Act 63	two component	unprimed steel/primed/ painted	trowel	24 hrs @ 77 ^{o}F	2-3 min -40-400F; ten 3600 psi
cyanoacrylate	Quantum 108	one component	steel	oily ok; wicks	instant 5-20 sec	not good in water

Table IV. Flexible Hose Applications and Approvals

HOSE TYPE	REINFORCE	WATER							OIL						GAS			APPROVALS
		FRESH	SALT	DEIONIZED	POTABLE	REACTOR EFFLUE	CONDENSATE	STEAM	OIL BASE	FIRE RESISTANT	WATER BASE	DIESEL	JP-5	LUBE	AIR	NITROGEN	REFRIGERANT	
SYNTHETIC RUBBER	2 WB	X	X			X	X		X		X	X		X				MIL-H-24135
SYNTHETIC RUBBER	TB / 4 SW	X	X				X		X		X	X		X				MIL-H-24135
SYNTHETIC RUBBER	TB / 4SW								X		X							MIL-H-24135
SYNTHETIC RUBBER	2 WB	X	X			X	X		X		X	X		X				MIL-H-24135 SAEJ1942
SYNTHETIC RUBBER	2 WB														X	X		MIL-H-24135 SAEJ1942
SYNTHETIC RUBBER	4 SW								X									MIL-H-24135 SAEJ1942
SYNTHETIC RUBBER	TB / 1WB /TB	X	X				X		X			X		X				MIL-H-24135 SAEJ1942
AQP	TB / 1WB	X	X				X		X			X		X	X	X		MIL-H-24135 SAEJ1942
AQP	2 WB	X	X			X	X		X			X		X				MIL-H-24135 SAEJ1942
SYNTHETIC RUBBER	TS	X	X				X		X			X		X				MIL-H-24136
SYNTHETIC RUBBER	TB	X	X				X		X			X		X				MIL-H-24136
SYNTHETIC RUBBER	TB	X	X				X		X			X		X				MIL-H-24136 J1942
SYNTHETIC RUBBER	TS	X	X				X					X		X				MIL-H-24136
SYNTHETIC RUBBER	TB	X	X						X			X	X	X				MIL-H-13444 TYPE 1
SYNTHETIC RUBBER	TB / 1WB								X			X		X				MIL-H-13444 TYPE III
SYNTHETIC RUBBER	WB	X	X										X	X	X			MIL-H-13531 TYPEI
SYNTHETIC RUBBER	2 WB								X			X	X	X				MIL-H-13531 TYPE II
SYNTHETIC RUBBER	WB																X	S6430-AE-TED-010
PTFE	SSB	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		MIL-H-38360 , AS1339
PTFE	SSB	X	X	X	X	X	X	X				X	X	X	X			SAE J 1942
CONVOLUTED PTFE	SSB	X	X	X	X	X	X	X				X	X	X	X			SAE J 1942
CONVOLUTED PTFE	SSB	X	X	X	X	X	X	X				X	X	X	X			SAE J 1942

WB = WIRE BRAID
TB = TEXTILE BRAID
SSB = STAINLESS STEEL BRAID

TS= TEXTILE SPIRAL
SW = SPIRAL WIRE
* SAE J 1942 = COAST GUARD APPROVAL

APPENDIX B

Milestone 2 Report

PRODUCIBILITY COST REDUCTIONS THROUGH ALTERNATIVE MATERIALS AND PROCESSES

Milestone 2 Report
Submitted to

Mr. William G. Becker
Newport News Shipbuilding
4101 Washington Avenue
Newport News, Virginia 23607

by

The University of Michigan
Transportation Research Institute

with

Avondale Industries Inc.

May 20, 1997

Principal Investigator:
Albert W. Horsmon, Jr.

Marine Systems Division
Transportation Research Institute
The University of Michigan
Ann Arbor, Michigan 48109-2150

Producibility Cost Reductions
Through Alternative Materials and Processes

The University of Michigan Transportation Research Institute (UMTRI), Marine Systems Division (MSD), along with Avondale Industries, Inc., Shipyards Division (Avondale), submits this Milestone 2 Report to Newport News Shipbuilding (NNS) as agreed in the Milestone Payment Schedule letter of January 11, 1996. This report is the “Potential Candidates List” and covers completion of

Task 3. Identify Potential Candidates.

A wide ranging list of items to be considered as alternatives in each of the interest areas was presented in the first milestone report. With the feedback and discussions generated from the previous milestone report, the candidate adhesives, flexible hose and PVC/GRP pipe to be tested and/or studied for potential cost and time savings were established. The project team presented a paper at the 1997 NSRP Ship Production Symposium that is a generic explanation of the project up to this stage. Additional feedback from invited discussants of the paper has been valuable and is referenced.

Adhesives

The Damilic Corporation has obtained a number of samples of adhesives likely to succeed in the project. Table III of the first milestone report listed a number of potential adhesives. This list was narrowed to the list in Table I below. Seven epoxies and four acrylic based adhesives were tested for their performance, ease of use, and compatibility between primed steel and a smooth aluminum surface, representative of the types of items to be bonded on a ship. Cyanoacrylates were not pursued because they are susceptible to hydrolytic attack.

Table I. Tested Adhesives

Epoxies	Acrylics
Lord 320	Hernon 761,730
TA-30	Lord 206/19
Epoxies, etc. 10-3005	AA 4325
Norcast FR 7316	Plexus MA310
Magnolia plastics	
Lord 310	
Armstrong A-12	

The preliminary screening of the selected adhesives was as follows. Primed steel plates 300 mm x 300 mm x 3 mm (12 in. x 12 in. x 0.125 in.) weighing roughly 2.3 kg (5 lbs.), representative of a ship's joiner bulkhead, were cleaned with acetone and scoured with an abrasive pad (to remove loose debris). The acetone removes most of any finish paint but only a minimal amount of primer. A generous amount of adhesive was applied to a small area on the steel plate (oriented horizontally) either through a syringe mixing applicator or with a putty knife (after mixing the two components by hand). The plate was then turned to stand vertically. A formed 0.1 mm (0.003 in.) aluminum foil cup was placed right side up on top of the adhesive. Hand pressure was applied to distribute the adhesive evenly between the aluminum / steel substrate pair. All of the adhesives except three (of relatively low viscosity) exhibited sufficient tack to support the aluminum on a vertical surface immediately after application. Following an overnight cure at room temperature, adhesive strength was tested by lifting up the whole steel plate by the rim of the foil cups. Of the eleven adhesives tested, five (Table II) bonded well enough to lift the whole steel plate. This was as much a tensile as a peel test. Values listed in the table are from separate and subsequent shear tests.

Table II. Adhesives Passing the Preliminary Test
and Tested for Lap Shear

Adhesive	Average Lap Shear Strength (psi)	Standard Deviation
AA4325	658	282
Lord 206/19	2631	484
TA-30 Philibond	2560	605
Norcast 2316	3270	142
Lord 320/322	2570	276

Following this test each adhesive assembly was placed in an hot and humid test chamber (an oven heated to 100°C (212°F) containing a pan of boiling water). The strength bearing capacity of the bonded aluminum and steel assembly was tested again. Four of the five adhesives (TA-30, Norcast FR2316, Lord 206/#19, and Lord 320/322) experienced no noticeable loss of strength. A slight loss of strength, exhibited as peeling, was observed for the AA 4325 adhesive.

For these five adhesives, laboratory lap shear specimens were prepared from 100 mm x 25 mm (4 in. x 1 in.) coupons machined from primed steel plate and tested according to ASTM D1002. In order to be accommodated by the grips in the tension testing machine, one end of each coupon was machined to a 1.6 mm (.06 in.) thickness. As before, surface preparation was limited to a solvent wipe with acetone and a mild scouring with an abrasive pad. Five lap shear specimens were prepared and tested for each of the five adhesives. The lap shear test results are shown in Table II.

In addition to their ability to bond to smooth and rough metal surfaces, a high initial tack makes these adhesives well suited to bonding applications on a vertical surface such as a bulkhead without temporary attachment aids or clamping.

The two component thixotropic paste epoxies can be applied either manually with a trowel or putty knife, or with manually or pneumatically operated dispensing equipment. The other epoxy adhesives are available in a double barrel syringe type applicator for small applications. The acrylic adhesive is also available in a higher viscosity so that it can be applied with a caulking gun. Our labor analyses will be based on powered and internal mixing applicators.

Based on the above results, the four highest strength adhesives have been selected for further testing at Avondale. These tests will involve more physical tests related to typical shipyard environments, and time and labor studies to compare their application to the established method of attachment that these adhesives may replace. We are also looking at the bond strength of the finish paint to determine how little surface preparation the adhesives can tolerate and still produce acceptable bond strength.

Flexible Hose

The first milestone report discussed the use of flexible hose in some applications but not in as many as may be expected from the allowable use tables from the classification societies. Comments from Glenn Ashe of ABS on our symposium paper showed that their latest rules (which came out after our first report) allow use of flexible hose in even more locations.

Our work on the flexible hose area is now centered on looking at comparative cost estimates between flexible hose and other systems for labor and materials. A typical example of these comparisons is provided in Appendix A where a copper nickel piping system is compared to a duplicate system in flexible hose. Table III summarizes these findings.

Table III. Savings of Flexible Hose over Cu-Ni Piping

Material	Labor Cost	Material Cost	Total
Cu-Ni	$6,275	$10,555	$16,830
Flexible Hose	$3,550	$10,711	$14,261
Savings (one system)	$2,725	($156)	**$2,569**

We have reviewed the potential list from the first report and are performing cost-benefit and labor analyses on those systems.

PVC/GRP Pipe

The PVC/GRP part of the project is headed the same way as the flexible hose part. We have collected and will dig for more cost comparisons between the plastic pipe and those metal pipe systems which it can safely replace. Similar to the flexible hose comparisons, the cost of using PVC or GRP pipe in place of traditional materials is being studied. Initial findings are promising that these plastics can be cost effective. Table IV looks at the comparative cost of relocating a single deck drain comparing a PVC/GRP replacement to that of steel.

Table IV. Savings of PVC/GRP Over Steel Piping

Material	Labor Cost	Material Cost	Total
Steel	$1,300	$17.32	$1,317
PVC/GRP	$1,150	$32.89	$1,183
Savings (one system)	$150	($15.57)	**$134**

We are doing similar cost-benefit and labor analyses to other candidate systems.

Regulatory

In parallel with the efforts on adhesives, flexible hose and PVC/GRP pipe, we are keeping up with the regulatory and class society requirements for these technologies. As cost-attractive alternatives are proven, regulatory issues will be addressed to smooth the way for official approvals related to specific shipbuilding contracts.

Conclusions

Initial findings of the team are that the alternative materials in the study are capable of reducing material and labor costs significantly in certain areas. Although this particular project is related to just adhesives, plastic and fiberglass pipe, and flexible hose, a methodology is being set up to consider the use of alternatives to traditional materials and methods in other areas of shipbuilding.

APPENDIX C

1997 Ship Production Symposium Paper

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306
Tel. (201) 798-4800 Fax. (201) 798-4975
Paper presented at the 1997 Ship Production Symposium, April 21-23, 1997
New Orleans Hilton Hotel, New Orleans, Louisiana

Producibility Cost Reductions Through Alternative Materials and Processes

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ABSTRACT

The competitive nature of shipbuilding requires that successful builders use the most cost effective means to construct their ships. This paper describes ongoing research to test the use of alternative materials and processes to reduce material and labor costs. Some of the traditional methods and materials used in shipbuilding are questioned and alternatives are evaluated. The research, backed by the NSRP through the SP-8, Industrial Engineering Panel of the SNAME Ship Production Committee, looks specifically at fiberglass and plastic pipe, adhesives and rubber hose as areas where cost and producibility gains may be found. Cost comparisons between traditional and alternative methods will be presented as well as applicability to regulatory and classification society requirements.

NOMENCLATURE

ASTM American Society for Testing and Materials
FRP Fiber Reinforced Plastic
GRP Glass Reinforced Plastic
NSRP National Shipbuilding Research Program
PVC Poly Vinyl Chloride
SNAME Society of Naval Architects and Marine Engineers
SP Ship Production Committee Panel

INTRODUCTION

The competitive nature of shipbuilding requires that successful builders use the most cost effective means to construct their ships. The SP-8, Industrial Engineering Panel of the Society of Naval Architects and Marine Engineers (SNAME) Ship Production Committee, frequently studies the mechanics of the ship production process and looks at ways to make the process more efficient and cost effective.

The SP-8 Panel developed the project as part of the National Shipbuilding Research Program's (NSRP) FY95 program to look specifically at fiberglass and plastic pipe, adhesives and rubber hose as alternatives to traditional materials and processes. This paper describes ongoing research conducted by the Marine Systems Division of the University of Michigan Transportation Institute, the Shipyards Division of Avondale Industries and Damilic Corporation, to investigate and test the use of alternative materials and processes to reduce the overall costs (including life cycle) of ships. For each of the subject focus areas of fiberglass and plastic pipe, adhesives and rubber hose, traditional methods and materials are questioned and alternatives are evaluated. The research task arrangement is as follows.

- Task 1. Identify Areas of Potential Use
- Task 2. Identify Function Specifications
- Task 3. Identify Potential Candidates
- Task 4. Test and Evaluate Candidates
- Task 5. Seek Regulatory Acceptance

The research team has established the most likely areas where adhesives, flexible hose and fiberglass pipe can be used to save significant time and cost. A preliminary list of items in each of the interest areas was developed and has been expanded through shipyard visits and discussions about the work of the project team and the SP-8 Panel. The first three tasks are nearly completed and on site testing is to follow shortly. Regulatory considerations are being checked in parallel.

The focus of the research is primarily on applications to commercial vessels, followed by naval auxiliaries and combatants. This research is in progress will be released as an NSRP report in the summer of 1997.

AREAS OF POTENTIAL USE

Adhesives

The adhesives area seems to be the most promising in the area of labor savings. The research is centering on the choice of adhesives that offer the best combination of holding power and ease of application without some of the negative attributes of volatile compounds (that would require additional ventilation, worker protection, or both) or excess preparation.

Adhesives bonding is an alternate means for mechanical fastening and welding non-structural and non-critical shipboard items. Adhesives also provide a means for easy on site repair or modification to fixtures. Potential shipboard applications for adhesives include clocks, thermostats, attachment of small diameter pipe and gauge tubing, label plates, brackets, and curtain plates (see Table I). These attachments can be exposed to temperatures between -18^{o}C and 49^{o}C (0 ^{o}F and 120^{o}F) and a relative humidity of 90% or more, during both installation and service life. Adhesives can be formulated to be either thermally conducting, electrically insulating or visa versa.

Bonded Items	Bond Area (sq. in.)	Comments
Curtain Plates	100-2000	Vertical placement, large surface area, good tack or green strength desired
Equipment Brackets	10-200	Vertical placement, high strength needed, long working time desired
Equipment Foundations	100-2000	Large volume application, strength and durability required
Insulation Mounting Clips	10-50	Long working time not necessary, good tack, medium strength, good temperature resistance
Label Plates	10-200	Long working time not necessary, low strength, good peel strength
Pipe Hangers	10-50	Intermediate fixturing time desirable, medium to high strength
Plumbing Fixtures	10-200	Low to medium strength, hydrophobic, attachment to plastics and other materials
Thermal/Acoustical Insulation	50-1500	Good tack, medium strength, good temperature resistance
Wire Hangers	10-50	Various levels of strength required, attachment over various substrates, easy attachment late in the building process
Zinc Anodes	50-250	Medium strength, electrically conductive, eliminates the need to weld stainless steel studs, eliminate chasing threads on studs for replacements

Table I - Candidates for Attachment by Adhesives.

Many forms of structural adhesives are available commercially. Table II describes the five most widely used chemically reactive structural adhesives (1):

- Epoxies,
- Urethanes,
- Acrylics,
- Cyanoacrylates, and
- Anaerobics.

Candidate adhesives were selected from a broad review of commercially available adhesives because of their general utility (Table III, page 4) and because they:

- Can be cured at ambient temperatures with minimal additional heat required,
- Pose minimal exposure hazard to workers, and
- Can be easily applied with a trowel, caulking gun, syringe, or gun dispenser.

Chemical Family	Advantages	Comments
Epoxy	High strength, good solvent resistance; good elevated temperature resistance; good gap filling capa-bilities; wide range of formulations	Ambient cure is almost always a two component system which requires either metering and premixing or dispensing equipment. Short pot life.
Polyurethane	Flexible, tough; is used in adhesive sealant formulations	Moisture sensitive; if purchased as a two component system one component is unreacted isocyanate - a toxic chemical
Acrylics	Good flexibility; peel and shear strength, will bond oily surfaces room temperature cure, moderate cost	Some are toxic and flammable (modified acrylics); more expensive than general purpose epoxies
Cyanoacrylate s	One component, good adhesion to metal, minimal quantities required	Instant cure limits fixturing time, low viscosity, good capillary action, more commonly known as super glue
Anaerobic	One component, long pot life, nontoxic	Thread locking adhesive, brand names include Locktite®

Table II Adhesives Types.

Adhesives Testing

From the list in Table III, seven epoxies and four acrylic based adhesives (Table IV) were tested for their performance, ease of use, and compatibility with primed steel and a smooth aluminum surface. Cyanoacrylates were not pursued because they are susceptible to hydrolytic attack.

Epoxies	Acrylics
Lord 320	Hernon 761,730
TA-30	Lord 206/19
Epoxies, etc 10-3005	AA 4325
Norcast FR 7316	Plexus MA310
Magnolia plastics	
Lord 310	
Armstrong A-12	

Table IV. Tested Adhesives.

The preliminary screening of the selected adhesives was as follows. Primed steel plates 300mm x 300mm x 3mm (12 in. x 12 in. x 0.125 in.) weighing roughly 2.3 kg (5 lbs.), representative of a ship's joiner bulkhead, were cleaned with acetone and scoured an abrasive pad (to remove loose debris). The acetone removes most of any finish paint but only a minimal amount of primer. A generous amount of adhesive was applied to a small area on the steel plate (oriented horizontally) either through a syringe mixing applicator or with a putty knife (after mixing the two components by hand). The plate was then turned to stand vertically. A formed 0.1mm (0.003 in.) aluminum foil cup was placed right side up on top of the adhesive. Hand pressure was applied to distribute the adhesive evenly between the substrate pair (aluminum / steel). All of the adhesives except three (relatively low viscosity) exhibited sufficient tack to support the aluminum on a vertical surface immediately after application. Following an overnight cure at room temperature, adhesive strength was tested by lifting up the steel by the rim of the foil cups. Of the eleven adhesives tested, five (Table V) bonded well enough to lift the whole steel plate. This was as much a tensile as a peel test.

Adhesive	Average Lap Shear Strength (psi)	Standard Deviation
AA4325	658	282
Lord 206/19	2631	484
TA-30 Philibond	2560	605
Norcast 2316	3270	142
Lord 320/322	2570	276

Table V. Adhesives Passing the Preliminary Test and Tested for Lap Shear.

Adhesive Type	Brand Name	Material Form	Applicable Substrate	Application Method	Cure Conditions	Special Features
epoxy	DAPCO 3004	two component	metal, wood, concrete, plastic	extrusion, trowel	4 hours	3,000 psi tensile strength
epoxy	Magnobond 6155	two component	plastic	trowel	7 days @ 70^{o}F	same as above
epoxy	Norcast 7285-1	one component	metals, plastics,	trowel	3 hrs @ 250^{o}F	fire retardant
epoxy	Norcast 9310	two component	general purpose	casting resin		
epoxy	Lord 310, 320	two component	steel, wood, FRP	syringe	24 hrs @ 77^{o}F	resists moisture, sunlight, thermal cycling, 320 is toughened for impact
epoxy	Epoxies, etc 10-3050	one component	steel	trowel	24 hrs @ 77^{o}F	8,000 psi tensile strength
modified acrylate	Advanced Adhesives Systems 4325	two component	primed steel/fiberglass	dispensing gun	24 hrs @ 77^{o}F	3,500 psi ten strength/ high humidity
acrylate	Dymax 828	liquid, two part	primed steel	brush or bead on	local pressure	3,000 psi ten strength/ 300^{o}F
epoxy	Armstrong A-12	liquid, two part	primed steel	brush or bead on	local pressure	Milspec epoxy, 2900 psi 300^{o}F
methacrylate	Plexus MA-310	liquid, two part	steel/fiberglass		local pressure	250^{o}F/tough
epoxy	Masterbond EP76M	liquid, two part	steel/fiberglass	trowel	24 hour @ 77^{o}F	300^{o}F
epoxy	Philadelphia Resins TA-30	two component	metal, rubber, wood, glass	trowel	24 hours @ 77^{o}F	very high tack
cyanoacrylate	Pacer Tech. M-100	100 cP liquid	primed steel	rough, clean	instant 30 sec	poor with moisture, brittle
cyanoacrylate	Pacer Tech. HP-500	5000 cP paste	general	brush on	1 min	
cyanoacrylate	R-X	thick	general	gel, paste	2 min	
epoxy	West Systems 105/205 hardener	two component	fiberglass, steel	hand mixed brush on	8-24 hrs @ 77^{o}F	no post cure, 200^{o}F no load 130^{o}F w/load
Polyester	ATC Chemical - Poly-bond B41F	two component	fiberglass, steel	thix. paste, putty knife, trowel	24 hrs @ 77^{o}F	tough, low shrinkage, used in FRP hull to deck marine applications
urethane	Sika 241	one component	steel, fiberglass,	gun dispenser	24 hrs @ 77^{o}F	semi permanent
urethane	3M Scotch-Seal 5200	one component	steel, fiberglass,	dispenser, trowel	24 hrs @ 77^{o}F	semi permanent
acrylic/Ag/Ni	3M 9703	tape	alcohol wipe, abrasion	40 psi pressure	72 hrs	conductive, 250^{o}F
methylmeth-acrylate mod	Hernon MI React 730; Act 56 and React 761; Act 63	two component	unprimed steel primed, painted	syringe appl bead on trowel (761)	24 hrs @ 77^{o}F	visc 6000 cps, 1-2 min fix time tensile str 3.000 psi/grit blast steel; -60^{o}F -250^{o}F; nonflammable
acrylic	Lord 206	two component	unprimed steel primed, painted	syringe type caulking gun	24 hour @ 77^{o}F	minimum prep, excellent moisture, temperature and UV resistance.
cyanoacrylate	Quantum 108	one component	steel	oily surfaces ok; wicking action	instant 5-20 sec	not good around water and moisture

Table III. Preliminary Adhesives Selection Table

Following this test the adhesive assembly was placed in an hot and humid test chamber (an oven heated to 100^{o}C (212^{o}F) containing a pan of boiling water). Using protective gloves, the strength bearing capacity of the bonded aluminum and steel assembly was tested again. Four of the five adhesives: TA-30, Norcast FR2316, Lord 206/#19, and Lord 320/322 experienced no noticeable loss of strength. A slight loss of strength, exhibited as peeling was observed for the AA 4325 adhesive.

For these five adhesives, laboratory lap shear specimens were prepared from 100 mm x 25 mm (4 in. x 1 in.) coupons machined from primed steel plate and tested according to ASTM D1002. In order to be accommodated by the grips in the tension testing machine, one end of each coupon was machined to a 1.6mm (.06 in.) thickness. As before, surface preparation was limited to a solvent wipe with acetone and a mild scouring with an abrasive pad. Five lap shear specimens were prepared and tested for each of the five adhesives. The lap shear test results are provided in Table V.

In addition to their ability to bond to smooth and rough metal surfaces, a high initial tack makes these adhesives ideally suited to bonding applications on a vertical surface such as a bulkhead.

Based on the above results, the four highest strength adhesives have been selected for further testing at the shipyard. The two component thixotropic paste epoxies can be applied either manually with a trowel or putty knife, or with pneumatically operated dispensing equipment. The other epoxy adhesives are available in a double barrel syringe type applicator. The acrylic adhesive is also available in higher viscosity so that it can be applied with a caulking gun.

Flexible Hose

The use of flexible hose in commercial and military shipbuilding has been approved by classification societies and regulatory bodies well beyond its current state of new construction general usage. With the advent of new materials, testing has been performed and approvals have been secured for the use of flexible hose in a number of areas. A general lack of awareness of the extent to which the use of flexible hose has been approved, coupled with the natural inclination of shipbuilders to retain the use of traditional shipbuilding practices and materials, has inhibited the widespread use of flexible hose to the extent allowable.

The research team has not discovered thorough studies that have analyzed the potential labor savings from the use of flexible hose to the extent allowable under current approvals. Table VI depicts the current areas of approval for various flexible hose applications.

In determining the suitability of flexible hose for a given application, hose assemblies are first classified as critical or non-critical depending on the system they are used in and the redundancy in that system. The level of criticality determines the replacement cycles for various hose assemblies and thereby contributes to determining the type of hose approved for use. In determining the level of criticality assigned to a given hose, the following attributes are considered and weighted as pertinent factors.

System. The system category is divided into five major sections, each reflecting a fluid type, except for drains, which are all inclusive.

- Gasses
- Water
- Sea water
- Drains
- Oil systems

Pressure Ratio. The pressure ratio is determined by dividing the rated working pressure of the hose by the system working pressure

Impulse. Impulse is defined as any pressure spike that momentarily raises the pressure in the hose.

Temperature. This is the working temperature range of the hose including the maximum temperature that the hose could be exposed to.

The project team is currently identifying and documenting those areas in which the use of flexible hose is acceptable according to classification societies and regulatory bodies, and comparing the potential use to actual existing standard shipyard practice. The potential labor savings and ancillary economies that could be recognized by fully adopting the use of flexible hose in all approved areas is being analyzed.

It is anticipated that the incorporation of flexible hose to the extent currently allowable in new ship construction would reduce manufacturing, modification, and repair costs as well as reduce vessel weight and reduce long term maintenance, operation and repair costs.

PVC/GRP Pipe

The use of Poly Vinyl Chloride (PVC) or Chlorinated PVC (CPVC), also called plastic pipe, and Glass Reinforced Plastic (GRP) or Fiber Reinforced Plastic (FRP), also called fiberglass, pipe on board commercial as well as military ships has proliferated substantially although sporadically over the past several years (2-5). While several recognized classification societies and regulatory bodies have approved the use of

		FRESH	SALT	DEIONIZED	POTABLE	REACTOR EFFLUENT	CONDENSATE	STEAM	OIL BASE	FIRE RESISTANT	WATER BASE	DIESEL	JP-5	LUBE	AIR	NITROGEN	REFRIGERANT	
HOSE TYPE	**REINFORCED**	**WATER**							**OIL**						**GAS**			**APPROVALS**
SYNTHETIC RUBBER	2 WB	X	X			X	X		X		X	X		X				MIL-H-24135
SYNTHETIC RUBBER	TB / 4 SW	X	X				X		X		X	X		X				MIL-H-24135
SYNTHETIC RUBBER	TB / 4SW								X		X							MIL-H-24135
SYNTHETIC RUBBER	2 WB	X	X			X	X		X		X	X		X				MIL-H-24135 SAEJ1942
SYNTHETIC RUBBER	2 WB														X	X		MIL-H-24135 SAEJ1942
SYNTHETIC RUBBER	4 SW								X									MIL-H-24135 SAEJ1942
SYNTHETIC RUBBER	TB / 1WB /TB	X	X				X		X			X		X				MIL-H-24135 SAEJ1942
AQP	TB / 1WB	X	X				X		X			X		X	X	X		MIL-H-24135 SAEJ1942
AQP	2 WB	X	X			X	X		X			X		X				MIL-H-24135 SAEJ1942
SYNTHETIC RUBBER	TS	X	X				X		X			X		X				MIL-H-24136
SYNTHETIC RUBBER	TB	X	X				X		X			X		X				MIL-H-24136
SYNTHETIC RUBBER	TB	X	X				X		X			X		X				MIL-H-24136 J1942
SYNTHETIC RUBBER	TS	X	X				X					X		X				MIL-H-24136
SYNTHETIC RUBBER	TB	X	X						X			X	X	X				MIL-H-13444 TYPE 1
SYNTHETIC RUBBER	TB / 1WB								X			X		X				MIL-H-13444 TYPE III
SYNTHETIC RUBBER	WB	X	X										X	X	X			MIL-H-13531 TYPEI
SYNTHETIC RUBBER	2 WB								X			X	X	X				MIL-H-13531 TYPE II
SYNTHETIC RUBBER	WB																X	S6430-AE-TED-010
PTFE	SSB	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		MIL-H-38360 , AS1339
PTFE	SSB	X	X	X	X	X	X	X				X	X	X	X			SAE J 1942
CONVOLUTED PTFE	SSB	X	X	X	X	X	X	X				X	X	X	X			SAE J 1942
CONVOLUTED PTFE	SSB	X	X	X	X	X	X	X				X	X	X	X			SAE J 1942

WB = WIRE BRAID
TB = TEXTILE BRAID
SSB = STAINLESS STEEL BRAID
TS= TEXTILE SPIRAL
SW = SPIRAL WIRE
* SAE J 1942 = COAST GUARD APPROVAL

Table VI. Flexible Hose Applications and Approvals fiberglass pipe in designated areas, other areas have not been addressed or do not currently have widespread approval.

The team's preliminary consideration for application of PVC and CPVC pipe is in:

- Potable water,
- Exterior deck drain,
- Low pressure air,
- Fresh water,
- Sea water washdown,
- Chill water,
- Hot water, and
- Sanitary drainage systems.

GRP pipe is likely to gain acceptance in the following systems:

- Seawater fire main,
- Seawater intake cooling,
- AFFF,
- Seawater overboard discharge,
- Oily water transfer,
- Crude oil washing ,
- Ballast tank flood and drain systems, and
- Cargo oil systems within tanks.

A chart of current approvals for GRP piping is listed in Table VII.

	ABS	USCG	LLOYDS	DNV
Inert gas (effluent overboard lines only through machinery or cofferdams)	YES	YES	YES	YES
Inert gas - distribution lines on deck	YES	YES	YES	YES
Sanitary / Sewage	YES	YES	YES	YES
Cargo piping - except on deck, in machinery spaces, and in pump rooms	YES	YES	YES	YES
Ballast system	YES	YES	YES	YES
Crude oil washing - in the tanks (not on deck)	YES	YES	YES	YES
Fire system	NO	NO	NO	NO
Cargo vent piping - within tanks only	YES	YES	YES	YES
Chilled and hot water system	YES	YES	YES	YES
Bilge system	NO	NO	NO	NO
Fresh and seawater cooling systems - aux.	YES	YES	YES	YES
Fresh and seawater cooling - vital	NO	NO	NO	NO
Cool steam condensate return system	YES	YES	YES	YES
Sounding tubes	YES	YES	YES	YES
Fire systems - offshore production platforms	N/A	N/A	N/A	N/A

Table VII. Classification Society and Regulatory Body Approval for GRP Pipe.

With the recent introduction of poly-siloxane modified phenolics in fiberglass pipe fabrication, a number of previously beneficial attributes of fiberglass pipe have been enhanced and a number of significant advances have been attained. At the same time, some heretofore negative characteristics have been mollified. Tables VIII and IX lists some of the positive and negative attributes of conventional phenolics an the newer poly-siloxane modified phenolic pipe materials.

A substantial amount of testing has been performed to verify the enhanced physical characteristics as well as improved fire performance of poly-siloxane modified phenolics. Among these tests are the following:

- IMO fire endurance testing - level 3 - eight tests carried out in two sizes and four configurations - in accordance with ASTM F1173 -95;
- SINTEF jet fire;
- ASTM E-84 - standard test method for surface burning characteristics of building materials;
- Pittsburgh toxicity;
- ASTM E-162 - test method for surface flammability of materials using a radiant heat energy source;

CONVENTIONAL PHENOLICS	
Positive Attributes	**Negative Attributes**
Excellent high temperature resistance	Poor adhesion for bonded joints
Low flame spread	Limited pressure performance due to low elongation and brittle nature
Corrosion resistance	Limited impact resistance
Low smoke and toxicity in fire	
Light weight	

Table VIII. Attributes of Phenolic Pipe

POLY-SILOXANE MODIFIED PHENOLICS	
Positive Attributes	**Negative Attributes**
All the same plus	To be seen.
Improved fire resistance	
Improved adhesion (160 %)	
Improved elongation (30 %)	
Improved impact resistance (40 %)	

Table IX. Attributes of Poly-Siloxane Modified Phenolic Pipe.

- ASTM E-662 - test method for specific optical density of smoke generated by solid materials;
- ASTM D-635 - rate of burning and/or extent of burning of self supporting plastics in a horizontal position;
- ASTM E-1354 - test method for heat and visible smoke release rates for materials and products using an oxygen consumption calorimeter;
- Lap shear strength physical;
- Short term burst;
- Hoop stress;
- Impact resistance;
- Flexural;.
- Modulus of elasticity;
- Chemical resistance;
- Weathering resistance;
- Steam resistance; and
- Corrosion resistance.

Comparison To Metallic Piping Systems. Compared to metallic piping systems, fiberglass, composite or plastic piping has a number of advantages. The following list shows some of the detractors of metallic materials compared to plastic.

- Carbon Steel is inherently corrosion prone and requires constant maintenance and frequent replacement. requires high level of installation and/or repair expertise.
- Copper Nickel has high initial material and installation cost but is costly to repair or modify and requires a high level of installation and repair expertise.
- Stainless Steel also has a high initial material and installation cost and is costly to repair or modify.
- Fiberglass Pipe has a moderate initial installation cost, will not corrode, has very low maintenance and a low skill level is adequate for installation. FRP pipe modification and repairs can be accomplished without certified welders, welding machines or burning equipment.

Table X is a comparison of the installed costs of a typical 100mm (4 in) offshore fire protection piping system.

Pipe System Material	Cost per Meter	Cost per Foot
Carbon Steel	\$82	\$25
Copper Nickel	\$295	\$90
Stainless Steel	\$312	\$95
Composite	\$115	\$35

Table X. Comparative Cost of a Fire Protection Piping System

The composite fire protection piping system, with intumescent coating, is capable of maintaining serviceability of the pipe for a minimum of three hours in a severe fire test. The life cycle advantages of the non-corroding composite pipe are expected to overcome the installed cost disadvantage.

With this type of performance available, the goal of the project is to promote the certification and approval of fiberglass pipe into areas currently not approved including:

- cargo piping,
- fire system piping,
- bilge systems,
- freshwater cooling,
- sea water cooling, and
- similar critical areas.

The project team is promoting the acceptability of fiberglass pipe for use on military vessels as already approved by non-military regulatory and classification societies.

The expanded incorporation of fiberglass pipe on both military and non-military vessels is expected to reduce manufacturing, modification, and repair costs as well as reduce vessel weights and lower long term maintenance and operation costs.

CONCLUSIONS

Initial findings of the team are that the alternative materials in the study are capable of reducing material and labor costs significantly in certain areas. Although this particular project is related to just adhesives, plastic and fiberglass pipe, and flexible hose, a methodology is being set up to consider the use of alternatives to traditional materials and methods in other areas of shipbuilding.

The use of adhesives to replace welding and mechanical attachments can save both material and labor costs. Adhesive strengths are adequate to support a number of shipboard items currently attached mechanically. The epoxies promise to provide base material protection so that make-up painting is not required.

Ongoing cost benefit analyses will determine the best applications of composite and plastic pipe and flexible hose. Fire protection and critical systems considerations are the focus of the research.

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APPENDIX D

Milestone 3 Report

PRODUCIBILITY COST REDUCTIONS THROUGH ALTERNATIVE MATERIALS AND PROCESSES

Milestone 3

Interim Test Report

Submitted to

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Newport News Shipbuilding
4101 Washington Avenue
Newport News, Virginia 23607

by

The University of Michigan
Transportation Research Institute

with

Avondale Industries Inc.

August 5, 1997

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Producibility Cost Reductions
Through Alternative Materials and Processes

The University of Michigan Transportation Research Institute (UMTRI), Marine Systems Division (MSD), along with Avondale Industries, Inc., Shipyards Division (Avondale), submits this milestone 3 report to Newport News Shipbuilding (NNS) as agreed in the milestone payment schedule letter of January 11, 1996. This report is the

Interim Test Report

and covers interim completion of the three-part

Task 4. Test and Evaluate Alternatives
- Test and Evaluate Adhesives
- Test and Evaluate Flexible Pipe and Hose
- Test and Evaluate PVC/GRP Pipe

Background

In the first milestone report, the "Area of Use and Function Report," two tasks were covered:

Task 1. Identify Areas of Potential Use, and
Task 2. Identify Function Specifications.

They established the most likely areas where adhesives, flexible hose, and PVC/GRP pipe can be used in commercial and naval ships to save significant time and cost. A preliminary list of items in each of the interest areas was presented. Our focus was (and still is) primarily on applications to commercial vessels, followed by naval auxiliaries and combatants.

In the second milestone report, candidate materials were obtained and evaluated against the acceptance criteria. Some thirty adhesives were evaluated and reduced to seven likely candidates. These were tested, and five candidates were obtained for further on-site testing at Avondale. Flexible hose and PVC/FRP pipe candidates were studied for cost, potential use and installation cost, and compared in detail to existing installations.

The project team presented a paper at the 1997 NSRP Ship Production Symposium in New Orleans that was a generic explanation of the project.

Additional feedback from invited discussants of the paper has been referenced for the testing phase and the regulatory acceptance task.

Task 4. Test and Evaluate Candidates.

This task is seen as the most critical in proving the concepts envisioned in the first three tasks. The materials and processes evaluated in the previous tasks are being evaluated based on the expectation that they will perform in this task. This task is broken down into the three process areas of adhesives, flexible hose and PVC/GRP pipe. Each process area includes a basic engineering analysis, a laboratory or simplified practical test component, and an on-site test at Avondale.

4-I. Adhesives

We have been able to test the candidate adhesives in the shock test apparatus at Avondale. Avondale provided primed steel plates with various coatings, such as primer and finish paint, to simulate applications of adhesives in various stages of production. Curtain plates, wire hangers and insulation hangers were used as samples of typical items to be bonded. We will not be able to test all candidates in a statistically valid exhaustive test series, but will be able to validate initial engineering calculations and previous tests for required performance. The shock test report follows as Appendix D-5 to 8.

Preliminary indications are that the adhesives work very well in the physical situations we have looked at. The main concerns now are the regulatory concerns of performance in fire, and identifying which systems are critical in fire. Cost benefit analyses are also being performed.

4-II. Flexible Pipe and Rubber or Composite Hose

As with adhesives, an ideal program of testing all candidates to ensure absolute reliability for shipboard use is beyond the scope and budget of this program. We have evaluated a number of flexible hose and pipe types through an educated engineering analysis to verify theoretical performance attributes claimed by various manufacturers. We are in the process of evaluating different attachment methods such as screwed, bolted flanges and hose clamps to establish adequate levels of performance for the various systems.

Avondale will measure the labor required for installing the hose or flexible pipe pieces and compare it to the previous method of application, likely a custom fitted bent pipe piece. A full labor and purchase cost benefit analysis will be performed for each tested arrangement. Appropriate physical testing will be performed at Avondale to validate the lab findings and engineering analyses. The results will be tabulated in the final report.

Regulatory requirements and allowances are fairly well established in this area, but extensions of the concepts are being investigated.

4-III. PVC/GRP Pipe

Avondale will lead this process area based on previous experience with many of these materials. PVC and GRP pipe and tube are already in use in many areas of ships, but not in any consistent volume. The thrust of this effort is to explore expanding this use. The previous milestone reports and the paper for the 1997 Ship Production Symposium discussed the attributes of different forms of plastic pipe.

In evaluating fiberglass pipe as an alternative to conventional pipe materials used in the shipbuilding process, a number of materials and production processes were evaluated. Polyester, vinyl ester, epoxy, phenolic and poly-siloxane modified phenolic resins were evaluated as were manufacturing processes that included centrifugal casting, hand lay-up and filament winding.

Among the various attributes that were considered in the evaluation were the following:

- corrosion resistance;
- temperature resistance;
- weight;
- flame spread and smoke generation;
- impact resistance;
- adhesion of bonded joints;
- method of joining;
- cost of installation;
- cost of repair and/or modification;
- skill level required for installation, repair, and/or modification;
- electrical conductivity; and
- maintenance requirements.

Fiberglass pipe was compared to carbon steel pipe, copper-nickel pipe, and stainless steel pipe. Several typical applications were evaluated and compared using the above criteria and estimated man-hours for typical installations. In order to accomplish this, comparable typical systems were designed in each of the aforementioned materials, and material as well as labor costs based on actual return costs on similar installations were compared.

Additionally, several different means of joining and connecting the fiberglass pipe are being evaluated to verify claimed or expected installation labor times. Different joining methods are being individually evaluated including flanged connections, bell and spigot, threaded and bonded, and butt and wrap. Appropriate physical testing will be performed at Avondale to validate the lab findings and engineering analyses. As with flexible hose and pipe, regulatory requirements seem well established in this area, but extensions of the concepts are being investigated.

Work continues.

ADHESIVES - SHOCK TESTING

ITEMS TESTED

1. INSULATION PINS - 2 in. x 2 in. perforated aluminum base with 5 in. protruding pin.

2. WIRE HANGER BASE - 2 in. diameter x 1/8 in. thick stainless steel base with protruding 3/8 in. stainless steel threaded stud.

3. CURTAIN PLATE - 3 in. x 4 in. x 1/8 in. mild steel plate. Curtain plate results are not reported on the attached charts as there were no curtain plate failures.

METHOD OF TESTING

A combination of 34 individual test items were attached to a 2 ft. x 3 ft. x 3/4 in. test plate using five different test adhesives. The test plate was subjected to a total of nine different shocks (three different load directions and three different intensities of shock). The shock load is generated by the controlled dropping of a 450 lb. pound weight from heights of one, three and five feet in three different axes. Three separate tests were conducted as follows.

TEST ONE

The shock test plate was bolted to a test plate foundation on a certified and calibrated shock test apparatus located at Avondale Shipyard, New Orleans, Louisiana. The 450 lb. test weight was dropped from heights of one, three, and five feet and impacted the test plate on the vertical edge of the plate, ninety degrees to the flat mounting surface of the face of the plate. Results of the test are reported in the following table marked test one.

TEST TWO

The shock test plate was mounted as before. The test weight was dropped from the same heights and impacted the test plate on the flat back side of the of the test plate. Results of the test are reported in the following table marked test two.

TEST THREE

The shock test plate was mounted as before. The test weight was dropped from the same heights and impacted the test plate on the top edge of the of the test plate. Results of the test are reported in the following table marked test three.

The steel plate used in the test was sand blasted, primed, and painted in accordance with standard navy-required procedures.

All failures experienced during the shock testing occurred in the bond line between the primer coat and the blasted steel surface. No failures were recorded in the adhesive bond line.

Table I. Test One - Side Impact

ADHESIVE	TYPE	SHOCK ONE INSULATION PIN	SHOCK TWO INSULATION PIN	SHOCK THREE INSULATION PIN
1. Philadelphia Resins TA - 30	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
2. Norcast FR 2316	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
3. 3M DP-190	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
4. Lord 206 /19	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
5. Lord 4910/19	Acrylic	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
6. Lord 310 A/ B	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
7. 3M Two Sided Tape 4941	Acrylic Foam	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0

ADHESIVE	TYPE	SHOCK ONE WIRE HANGER BASE	SHOCK TWO WIRE HANGER BASE	SHOCK THREE WIRE HANGER BASE
1. Philadelphia Resins TA - 30	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
2. Norcast FR 2316	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
3. 3M DP-190	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
4. Lord 206 /19	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
5. Lord 4910/19	Acrylic	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
6. Lord 310 A/ B	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 **FAILURES - 2**
7. 3M Two Sided Tape 4941	Acrylic Foam	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0

Table II. Test Two - Back Side Impact

ADHESIVE	TYPE	SHOCK ONE INSULATION PIN	SHOCK TWO INSULATION PIN	SHOCK THREE INSULATION PIN
1. Philadelphia Resins TA - 30	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
2. Norcast FR 2316	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
3. 3M DP-190	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
4. Lord 206 /19	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
5. Lord 4910/19	Acrylic	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
6. Lord 310 A/ B	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 **FAILURES - 1**	TEST ITEMS - 4 FAILURES - 0
7. 3M Two Sided Tape 4941	Acrylic Foam	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0

ADHESIVE	TYPE	SHOCK ONE WIRE HANGER BASE	SHOCK TWO WIRE HANGER BASE	SHOCK THREE WIRE HANGER BASE
1. Philadelphia Resins TA - 30	Epoxy	TEST ITEMS - 4 **FAILURES - 2**	TEST ITEMS - 2 **FAILURES - 2**	TEST ITEMS - 0 FAILURES - 0
2. Norcast FR 2316	Epoxy	TEST ITEMS - 4 **FAILURES - 2**	TEST ITEMS - 2 **FAILURES - 2**	TEST ITEMS - 0 FAILURES - 0
3. 3M DP-190	Epoxy	TEST ITEMS - 4 **FAILURES - 2**	TEST ITEMS - 2 **FAILURES - 2**	TEST ITEMS - 0 FAILURES - 0
4. Lord 206 /19	Epoxy	TEST ITEMS - 4 **FAILURES - 2**	TEST ITEMS - 2 **FAILURES - 2**	TEST ITEMS - 0 FAILURES - 0
5. Lord 4910/19	Acrylic	TEST ITEMS - 4 **FAILURES - 2**	TEST ITEMS - 3 **FAILURES - 2**	TEST ITEMS - 1 **FAILURES - 1**
6. Lord 310 A/ B	Epoxy	TEST ITEMS - 4 **FAILURES - 2**	TEST ITEMS - 2 **FAILURES - 2**	TEST ITEMS - 0 FAILURES - 0
7. 3M Two Sided Tape 4941	Acrylic Foam	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0

Table III. Test Three - Top Edge Impact

ADHESIVE	TYPE	SHOCK ONE INSULATION PIN	SHOCK TWO INSULATION PIN	SHOCK THREE INSULATION PIN
1. Philadelphia Resins TA - 30	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
2. Norcast FR 2316	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
3. 3M DP-190	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
4. Lord 206 /19	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
5. Lord 4910/19	Acrylic	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
6. Lord 310 A/ B	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
7. 3M Two Sided Tape 4941	Acrylic Foam	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0

ADHESIVE	TYPE	SHOCK ONE WIRE HANGER BASE	SHOCK TWO WIRE HANGER BASE	SHOCK THREE WIRE HANGER BASE
1. Philadelphia Resins TA - 30	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
2. Norcast FR 2316	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
3. 3M DP-190	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
4. Lord 206 /19	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
5. Lord 4910/19	Acrylic	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0
6. Lord 310 A/ B	Epoxy	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 **FAILURES - 2**
7. 3M Two Sided Tape 4941	Acrylic Foam	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0	TEST ITEMS - 4 FAILURES - 0

APPENDIX E

Milestone 4 Report

PRODUCIBILITY COST REDUCTIONS THROUGH ALTERNATIVE MATERIALS AND PROCESSES

Milestone 4

Final Test Report

Submitted to

Mr. William G. Becker
Newport News Shipbuilding
4101 Washington Avenue
Newport News, Virginia 23607

by

The University of Michigan
Transportation Research Institute

with

Avondale Industries Inc.

August 13, 1998

Principal Investigator:
Albert W. Horsmon, Jr.

Marine Systems Division
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Producibility Cost Reductions
Through Alternative Materials and Processes

The University of Michigan Transportation Research Institute (UMTRI), Marine Systems Division (MSD), along with Avondale Industries, Inc., Shipyards Division (Avondale), submits this Milestone 4 Report to Newport News Shipbuilding (NNS). This report is the

Final Test Report

and covers completion of the three-part Task 4, to test and evaluate alternatives.

Background

In the first milestone report, the "Area of Use and Function Report," two tasks were covered:

Task 1. Identify Areas of Potential Use, and
Task 2. Identify Function Specifications.

They established the most likely areas where adhesives, flexible hose, and PVC/GRP pipe can be used in commercial and naval ships, to save significant time and cost.

In the second milestone report, candidate materials were obtained and evaluated against the acceptance criteria to complete

Task 3. Identify Potential Candidates.

Some thirty adhesives were evaluated and reduced to seven likely candidates. These were tested and five obtained for further on-site testing at Avondale. Flexible hose and PVC/FRP pipe candidates were studied for material cost, potential use and installation cost, and compared in detail to existing installations.

The third milestone report, the Interim Test Report, was a report on

Task 4. Test and Evaluate Candidates.

This fourth milestone report is the Final Test Report. To follow are

Task 5. Seek Regulatory Acceptance, and

Task 6. Produce Final Report

which will be covered in the Milestone 5 Draft Final Report and Milestone 6 Final Report.

Task 4. Test and Evaluate Candidates.

This task is seen as the most critical in proving the concepts envisioned in the first three tasks. The materials and processes evaluated in the previous tasks were evaluated based on the expectation that they would perform in this task. This task is broken down into the three process areas of adhesives, flexible hose and PVC/GRP pipe.

4-I. Adhesives

We have been able to test the candidate adhesives in the shock test apparatus at Avondale. The adhesives worked very well in the physical models studied. Bond strength of the selected adhesives to cleaned steel surfaces were reported previously and are in the range of 2,000 to 3,000 psi. The shock test failures noted in the previous report were not in the adhesives, but in the bond between the primer paint and the steel plate (adhesion), or in the paint layers (cohesion) below the adhesive. However, it was decided earlier in the project that the following factors prohibit paint removal as part of the adhesive application process:

- paint removal involves additional labor that takes more time (and adds cost);
- as a manual process, additional variables are involved that limit use of the optimum strength afforded by the best adhesives; and
- paint removal chemicals introduce volatile organic compounds (VOCs) and require special handling.

Thus, the use of adhesives over the existing paint systems became the limiting strength factor in the use of adhesives.

Various paint adhesion and cohesion factors were studied to determine the limiting strength factors for bonds to painted surfaces. The following pull strengths were measured according to ASTM D 4541-93, Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers.

Table I. Paint Adhesion and Cohesion

Coating Type	Failure	Strength (psi)
Valspar Sovapon Epoxy	Cohesive	450
Valspar Sovapon Epoxy	Cohesive	550
Valspar Sovapon Epoxy	Cohesive	400
Ameron 3207 primer	none	850
Amercoat 180A Synthetic Resin Coating	Cohesive	200
Amercoat 180A Synthetic Resin Coating	Cohesive	200
Carboline 8101 Acrylic Primer	none	850

With this variability in paint adhesion and/or cohesion strength, an additional study would be needed to optimize paint strength if that becomes the limiting factor for adhesives applications. The primer strength is quite high, so proper planning for adhesives application in the construction sequence before final paint would allow use of the higher strength.

4-II. Flexible Pipe and Rubber or Composite Hose
4-III. PVC/GRP Pipe

Avondale has measured the labor and material required for installing the hose or flexible pipe pieces, and PVC and GRP pipe and tube, and compared those figures to traditional materials and methods of application. Full labor and purchase cost benefit analyses are in Tables III through VI at the end of this report. Table II is the summary of the findings showing the initial installation advantages of the composite and plastic materials. Additional comparisons will be in the final report.

Table II. Summary Cost Comparison

	LABOR	MATERIAL	TOTAL
STEEL	**$32,165**	**$6,495**	**$38,660**
COPPER NICKEL	**$32,165**	**$13,471**	**$45,636**
GRP	**$23,115**	**$19,634**	**$42,749**
PVC	**$12,965**	**$4,870**	**$17,835**

Table III. Deck Drain Material List - Copper Nickel

QUANTITY	PART NO.	DESCRIPTION	COST EA.	TOTAL
58 FT.	000066308	1 1/2" TUBE 90-10 SMLS CUNI	4.20	243.60
198 FT.	000066309	2" TUBE 90-10 SMLS CUNI	6.28	1243.44
313 FT.	000066311	3" TUBE 90-10 SMLS CUNI	10.97	3433.61
136 FT.	000066322	4" TUBE 90-10 SMLS CUNI	17.30	2352.80
40 FT.	000066314	5" TUBE 90-10 SMLS CUNI	25.69	1027.60
20 FT.	000066315	6" TUBE 90-10 SMLS CUNI	35.13	702.60
1 EA.	000098649	3" 90 /ELL 90-10 CUNI	28.00	28.00
1 EA.	000122270	3' X 2" REDUCER 90-10 CUNI	21.47	21.47
2 EA.	000122928	4" X 2"" REDUCER 90-10 CUNI	38.0	76.00
2 EA.	000122298	4' X 3"" REDUCER 90-10 CUNI	48.87	97.74
2 EA.	000012690	5' X3" REDUCER 90-10 CUNI	44.68	89.36
8 EA.	000129074	1 1/2 " SLIP ON SLEEVE 90-10 CUNI	4.40	35.20
19 EA.	000129070	2 " SLIP ON SLEEVE 90-10 CUNI	4.90	93.10
38 EA.	000129072	3" SLIP ON SLEEVE 90-10 CUNI	7.00	266.00
10 EA.	000129075	4 " SLIP ON SLEEVE 90-10 CUNI	10.40	104.00
2 EA.	000129076	5 " SLIP ON SLEEVE 90-10 CUNI	16.31	32.62
4 EA.	000180333	1 1/2" DECK DRAIN BW STL TATE 60-100A	45.00	180.00
9 EA.	000180358	2" DECK DRAIN BW STL TATE 60-100C	49.19	442.71
10 EA.	000180351	3" DECK DRAIN BW STL TATE 60-100H	72.86	728.60
2 EA.	000180047	4" DECK DRAIN BW STL TATE 60-100K	88.00	176.00
2 EA.	000180050	6" DECK DRAIN SW STL TATE 60-100W	223.59	447.18
4 EA.	000180097	1 1/2" NPS DECK DRAIN ASSY. MS-06-DD-01	75.00	300.00
5 EA.	000180062	2" NPS DECK DRAIN ASSY. MS-06-DD-01	79.19	395.95
4 EA.	000180063	3" NPS DECK DRAIN ASSY. MS-06-DD-01	89.00	356.00
12 EA.	906PH0705	1 1/2" NPS PIPE SUPP. U-BOLT M5-06-PH-07	3.30	39.60
30 EA.	906PH0706	2" NPS PIPE SUPP. U-BOLT M5-06-PH-07	3.30	99.00
40 EA.	906PH0708	3" NPS PIPE SUPP. U-BOLT M5-06-PH-07	6.96	278.40
17 EA.	906PH0709	4" NPS PIPE SUPP. U-BOLT M5-06-PH-07	6.96	118.32
4 EA.	906PH0710	5" NPS PIPE SUPP. U-BOLT M5-06-PH-07	8.85	35.40
3 EA.	906PH0711	6" NPS PIPE SUPP. U-BOLT M5-06-PH-07	8.95	26.85
		MATERIAL TOTAL		13,471.15

Table IV. Deck Drain Material List – Steel

QUANTITY	PART NO.	DESCRIPTION	COST EA.	TOTAL
58 FT.	000062108	1 1/2" STEEL PIPE SCHED. 40 ASTM 106 GR. A&B	1.14	66.12
198 FT.	000063309	2" STEEL PIPE SCHED. 40 ASTM 106 GR. B	1.29	255.42
313 FT.	000063311	3" STEEL PIPE SCHED. 40 ASTM 106 GR. B	2.75	860.75
136 FT.	000063313	4" STEEL PIPE SCHED. 40 ASTM 106 GR.B	3.62	492.32
40 FT.	000063314	5" STEEL PIPE SCHED. 40 ASTM 106 GR.B	4.36	174.40
20 FT.	000063315	6" STEEL PIPE SCHED. 40 ASTM 106 GR.B	6.60	132.00
4 EA.	000180333	1 1/2" DECK DRAIN BW STL TATE 60-100A	45.00	180.00
9 EA.	000180358	2" DECK DRAIN BW STL TATE 60-100C	49.19	442.71
10 EA.	000180351	3" DECK DRAIN BW STL TATE 60-100H	72.86	728.60
2 EA.	000180047	4" DECK DRAIN BW STL TATE 60-100K	88.00	176.00
2 EA.	000180050	6" DECK DRAIN SW STL TATE 60-115W	223.59	447.18
1 EA.	000091311	ELBOW - 90 BW STL ASTM A234 GR WPB	4.00	4.00
1 EA.	000120123	REDUCER - 3" X 2" BW ASTM A234 SCHED. 40	3.50	3.50
2 EA.	000120131	REDUCER - 4" X 2" BW ASTM A234 SCHED. 40	5.04	10.08
2 EA.	000120133	REDUCER - 4" X 3" BW ASTM A234 SCHED. 40	5.15	10.30
2 EA.	000120137	REDUCER - 5" X 3" BW ASTM A234 SCHED. 40	8.04	16.08
19 EA.	000180877	2" SLV. SLIP ON WELDED ASTM F682 TY 2	4.48	35.84
38 EA.	000180879	3" SLV. SLIP ON WELDED ASTM F682 TY 2	5.03	95.57
10 EA.	000180881	4" SLV. SLIP ON WELDED ASTM F682 TY 2	6.96	696.00
2 EA.	000180890	5" SLV. SLIP ON WELDED ASTM F682 TY 2	9.13	18.26
4 EA.	000180097	1 1/2" NPS DECK DRAIN ASSY. MS-06-DD-01	75.00	300.00
5 EA.	000180062	2" NPS DECK DRAIN ASSY. MS-06-DD-01	79.19	395.95
4 EA.	000180063	3" NPS DECK DRAIN ASSY. MS-06-DD-01	89.00	356.00
12 EA.	906PH0705	1 1/2" NPS PIPE SUPP. U-BOLT M5-06-PH-07	3.30	39.60
30 EA.	906PH0706	2" NPS PIPE SUPP. U-BOLT M5-06-PH-07	3.30	99.00
40 EA.	906PH0708	3" NPS PIPE SUPP. U-BOLT M5-06-PH-07	6.96	278.40
17 EA.	906PH0709	4" NPS PIPE SUPP. U-BOLT M5-06-PH-07	6.96	118.32
4 EA.	906PH0710	5" NPS PIPE SUPP. U-BOLT M5-06-PH-07	8.85	35.40
3 EA.	906PH0711	6" NPS PIPE SUPP. U-BOLT M5-06-PH-07	8.95	26.85
		MATERIAL TOTAL		6,494.65

Table V. Exterior Deck Drain System – GRP

QUANTITY	PART NO.	DESCRIPTION	COST EA	TOTAL
58 FT.	QO753862	1 1/2" POLYSILOXANE / PHENOLIC FRP PIPE	16.00/FT.	928.00
198 FT.	20754263	2" POLYSILOXANE / PHENOLIC FRP PIPE	7.40 /FT.	1,465.20
313 FT.	30754263	3" POLYSILOXANE / PHENOLIC FRP PIPE	9.10 / FT.	2,848.30
136 FT.	40754263	4" POLYSILOXANE / PHENOLIC FRP PIPE	11.70/FT.	1,591.20
60 FT.	60754263	6" POLYSILOXANE / PHENOLIC FRP PIPE	17.60/FT.	1,056.00
4 EA.	000180333	1 1/2" DECK DRAIN TATE 60-100A OR EQUAL	45.00	180.00
9 EA.	000180358	2" DECK DRAIN TATE 60-100C OR EQUAL	49.19	442.71
10 EA.	000180351	3" DECK DRAIN TATE 60-100H OR EQUAL	72.86	728.60
2 EA.	000180047	4" DECK DRAIN TATE 60-100K OR EQUAL	88.00	176.00
2 EA.	000180050	6" DECK DRAIN TATE 60-100W OR EQUAL	223.59	447.18
1 EA.	30752060	3" ELB. 90 FRP	78.80	78.80
1EA.	32757660	3" x 2" REDUCER	82.80	82.80
2 EA.	42757660	4" x 2' REDUCER	105.20	210.40
2 EA.	43757660	4" x 3" REDUCER	100.10	200.20
2 EA.	63757660	6" x 3" REDUCER	147.20	294.40
8 EA.	Q0750760	1 1/2" COUPLING POLYSIXANE / PHENOLIC FRP	12.70	101.60
19 EA.	20750760	2" COUPLING POLYSILOXANE / PHENOLIC FRP	18.40	349.60
38 EA.	30750760	3" COUPLING POLYSILOXANE / PHENOLIC FRP	20.70	786.60
10 EA.	40750760	4" COUPLING POLYSILOXANE / PHENOLIC FRP	24.20	242.00
2 EA.	60750760	6" COUPLING POLYSILOXANE / PHENOLIC FRP	42.60	83.20
4 EA.	000180097	1 1/2" NPS DECKDRAIN ASSY. MS-06-DD-01	75.00	300.00
5 EA.	000180062	2" NPS DECKDRAIN ASSY. MS-06-DD-01	79.19	395.95
4 EA.	000180063	3" NPS DECKDRAIN ASSY. MS-06-DD-01	89.00	356.00
4 EA.	Q0751460	1 1/2" 45 ELBOW - FRP	47.20	188.80
25 EA.	20751460	2" 45 ELBOW - FRP	55.20	1,380.00
35 EA.	30751460	3" 45 ELBOW - FRP	78.80	2,758.00
2 EA.	40751460	4" 45 ELBOW - FRP	123.10	246.20
2 EA.	60751460	6" 45 ELBOW - FRP	190.90	381.80
3 EA.	26757009	2 BLANK SADDLE	25.30	75.90
6 EA.	36757009	3" BLANK SADDLE	26.50	159.00
1 EA.	4Q757105	4" x 1 1/2" BLANK SADDLE	124.20	124.20
12 EA.	906PH0705	1 1/2" NPS PIPE SUPP. - U-BOLT - MS-06-PH-07	3.30	39.60
30 EA.	906PH0706	2" NPS PIPE SUPPORT - U-BOLT - MS-06-PH-07	3.30	99.00
40 EA.	906PH0708	3" NPS PIPE SUPPORT - U-BOLT - MS-06-PH-07	6.96	278.40
17 EA.	906PH0709	4" NPS PIPE SUPPORT - U-BOLT - MS-06-PH-07	6.96	118.32
7 EA.	906PH0710	6" NPS PIPE SUPPORT - U-BOLT - MS-06-PH-07	8.95	62.65
42 EA.	000171381	HOSE CLAMP 2 1/16" x 3"	.75	31.50
28 EA.	000170131	HOSE CLAMP 3 1/16" x 4"	.44	12.32
2 EA.	000170907	HOSE CLAMP 4 1/8" x 5"	1.03	2.06
2 EA.	NTV627MC05	HOSE CLAMP 6 1/8" x 7"	2.00	4.00
8 FT.	000171373	1 1/2" RUBBER CLOTH INSERTED HOSE	5.65	45.20
13 FT.	000171374	2" RUBBER CLOTH INSERTED HOSE	8.58	111.54
14 FT.	000171320	3" RUBBER CLOTH INSERTED HOSE	9.34	131.32
2 FT.	000171320	4" RUBBER CLOTH INSERTED HOSE	9.34	18.68
2 FT.	000993484	6" RUBBER CLOTH INSERTED HOSE	10.46	20.92
		MATERIAL TOTAL		19,634.15

Table VI. Exterior Deck Drain Material – PVC

QUANTITY	UNIT	DESCRIPTION	COST EA.	TOTAL
58	FT.	1 1/2 " SCHED. 40 PVC PIPE	0.27	15.66
198	FT.	2 " SCHED. 40 PVC PIPE	0.38	75.24
313	FT.	3 " SCHED. 40 PVC PIPE	0.89	278.57
136	FT.	4 " SCHED. 40 PVC PIPE	1.91	259.76
40	FT.	5 " SCHED. 40 PVC PIPE	2.25	90
20	FT.	6 " SCHED. 40 PVC PIPE	2.9	58
1	EA.	3 " 90 / ELL	2.95	2.95
1	EA.	3" X 2" REDUCER	3.95	3.95
2	EA.	4" X 2" REDUCER	4.36	8.72
2	EA.	4" X 3" REDUCER	4.95	9.9
2	EA.	5" X 3" REDUCER	5.64	11.28
8	EA.	1 1/2 " SLEEVE	0.83	6.64
19	EA.	2 " SLEEVE	1.14	21.66
38	EA.	3 " SLEEVE	2.67	101.46
10	EA.	4 " SLEEVE	5.73	57.3
2	EA.	5 " SLEEVE	6.75	13.5
12	906PH0705	1 1/2 " NPS PIPE SUPPORT U-BOLT MS-06-PH-07	3.3	39.6
30	906PH0706	2 " NPS PIPE SUPPORT U-BOLT MS-06-PH-07	3.3	99
40	906PH0708	3 " NPS PIPE SUPPORT U-BOLT MS-06-PH-07	6.96	278.4
17	906PH0709	4 " NPS PIPE SUPPORT U-BOLT MS-06-PH-07	6.96	118.32
7	906PH0710	6 " NPS PIPE SUPPORT U-BOLT MS-06-PH-07	8.95	62.65
8	000171373	1 1/2 " RUBBER CLOTH REINFORCED HOSE	5.65	45.2
13	000171374	2 " RUBBER CLOTH REINFORCED HOSE	8.58	111.54
14	000171320	3 " RUBBER CLOTH REINFORCED HOSE	9.34	130.76
2	000171320	4 " RUBBER CLOTH REINFORCED HOSE	9.34	18.68
2	000993484	6 " RUBBER CLOTH REINFORCED HOSE	10.46	20.92
42	000171381	HOSE CLAMP S/S 2 1/16 " - 3 "	0.75	31.5
28	000170131	HOSE CLAMP S/S 3 1/16 " - 4 "	0.44	12.32
2	000170907	HOSE CLAMP S/S 4 1/8 " - 5 "	1.03	2.06
2	NTV627MCO5	HOSE CLAMP S/S 6 1/8 " - 7 "	2	4
4	60-100A	1 1/2 " DECK DRAIN BW STL	45	180
9	60-100C	2 " DECK DRAIN BW STL	49.19	442.71
10	60-100H	3 " DECK DRAIN BW STL	72.86	728.6
2	60-100K	4 " DECK DRAIN BW STL	88	176
2	60-115W	6 " DECK DRAIN BW STL	223.59	447.18
1	MS-06-DD-01	1 1/2 " NPS DECK DRAIN ASSY.	75	75
6	MS-06-DD-01	2 " NPS DECK DRAIN ASSY.	79.19	475.14
4	MS-06-DD-01	3 " NPS DECK DRAIN ASSY.	89	356
		MATERIAL TOTAL		4870.17

Table VII. Exterior Deck Drain - Summary System Installation - Labor and Material Analysis

GRP - POLY SILOXANE MODIFIED PHENOLIC				
	UNITS	M/H UNIT	TOTAL M/H	DOLLARS
FABRICATION - PIPE DETAILS	96 PD	3.2	308	7,700.00
INSTALLATION - ON UNIT	459 FT.	0.35	161	4,025.00
WELDING ON UNIT (HANGERS, DRAIN)	N/A	N/A	28	700.00
INSTALLATION ON BOARD	306 FT.	0.76	233	5,825.00
WELDING ONBOARD (HANGERS)	N/A	N/A	11	275.00
TESTING	765 FT.	0.24	183.6	4,590.00
	TOTAL	LABOR	924.6	23,115.00
	TOTAL	MATERIAL		19,634.15
	TOTAL	GRP		42,749.15

COPPER - NICKELAND STEEL PIPE				
	UNITS	M/H UNIT	TOTAL M/H	DOLLARS
FABRICATION - PIPE DETAILS	96 PD	3.2	308	7,700.00
INSTALLATION - ON UNIT	459 FT.	0.45	207	5,175.00
WELDING ON UNIT (HANGERS, DRAIN)	459 FT.	0.15	70	1,750.00
INSTALLATION ON BOARD	306 FT.	1.25	383	9,575.00
WELDING ONBOARD (HANGERS)	306	0.44	135	3,375.00
TESTING	765 FT.	0.24	183.6	4,590.00
	TOTAL	LABOR	1286.6	32,165.00
	TOTAL	MATERIAL	CU-NI	13,471.15
	TOTAL	CU-NI		45,636.15
	TOTAL	MATERIAL	Steel	6,494.65
	TOTAL	STEEL		38,659.65

PVC PIPE				
	UNITS	M/H UNIT	TOTAL M/H	DOLLARS
FABRICATION - PIPE DETAILS	96 PD		0	0.00
INSTALLATION - ON UNIT	459 FT.	0.27	126	3,150.00
WELDING ON UNIT (HANGERS, DRAIN)	N/A	N/A	22	550.00
INSTALLATION ON BOARD	306 FT.	0.58	176	4,400.00
WELDING ONBOARD (HANGERS)	N/A	N/A	11	275.00
TESTING	765 FT.	0.24	183.6	4,590.00
	TOTAL	LABOR	518.6	12,965.00
	TOTAL	MATERIAL		4,870.17
	TOTAL	PVC		17,835.17

NO BENEFIT IS CALCULATED FOR THE PAY RATE DIFFERENTIAL BETWEEN WELDERS AND FRP LAMINATORS. CALCULATIONS ARE BASED ON A LABOR RATE OF $25.00 PER HOUR.

APPENDIX F

Naval Joining Center Letters

October 22, 1997

Albert W. Horsmon, Jr.
University of Michigan Transportation Research Institute
Marine Systems Division
2801 Baxter Road
Ann Arbor, MI 488109-2150

EWI Project No. 41961CSP, Review of Marine Bonding Tests

Dear Mr. Horsmon:

I have reviewed the reports and article you sent to me and have several comments included in this letter. I am not sure I have all the tables and appendices. Some of them seem to be missing from the E-mailed files of the reports. If you could send hard copies of the reports, I would appreciate that.

I didn't have much test data to review other than some lap shear screening data. If there is more information on humidity or other environmental effects, I would like to see that. Raw data are fine. For example, you mention the hot/wet test but don't give a duration. Hot/wet data are typically obtained after three weeks exposure to 60^{o}C/98-100% RH. Unpainted steel rusts badly under these conditions and it gives the bondlines a real workout, if the steel survives at all. I like to include exposure to sea water, usually in the form of a relatively short duration soak. In the humidity cycle, I throw in an 8-hour soak in salt water and then return the samples to hot/wet. I might do this every three or four days. It isn't uncommon for an epoxy to lose 40% strength under these conditions.

I don't know if you are aware of the work of the Glasgow Marine Technology Centre at the University of Glasgow in Scotland, UK. They have done studies on bonding of composites and fire ratings for service mostly on off-shore oil rigs. I have some information on the way but they may be worth contacting for your work. Their Internet address is www.eng.gla.ac.uk/marine/adhesiv.htm and their E-mail is (lynnc@eng.gla.ac.uk). PH: +44-(0)141-339 0969 and FAX: +44-(0)141-330-4015.

As to the specifics of the information, much of is seems to be in good order. The applications you envision are not very demanding. Most involve large bond areas with low mass objects. Many are non-critical attachments. Here are some general comments.

- It is common to be bonding to cold surfaces. We have added testing cycles where we cure the adhesive at 40^{o}F in a refrigerator. In our case, we didn't see much difference but you want to make sure whatever adhesive you choose will cure at low temperatures and still function.

- I have found that acrylics may have objectionable odor and sometimes give spotty cures in thin films. I include MSDS information and HMIS data as part of my screening. I don't like to recommend adhesives with health ratings above 2 and flammability ratings of 3 or higher. I consider objectionable odor as a grounds for disqualification because repairs or fixturing may be done in confined spaces on a "buttoned up" ship tossing around the North Atlantic. Those guys will be sick enough already.

- When bonding on vertical surfaces, tape can be used to fixture parts while they cure. This may offer more help when slump resistance is an issue.

- In most of the work I'm doing, we now assume the adhesive bonding will be done to painted, primed steel. This means the paint adhesion will be the determining factor in bond strength unless mechanical augmentation is used. The advantage is it eliminates the need for separate surface preparation in bonded areas only. We now include paint adhesion studies as part of the overall test scheme in looking at joint design. If bonding to bare steel, it should be sandblasted to near-white metal and then phosphated.

- Pipes
    - Phenolic has excellent fire resistant properties and you are probably aware of its use on submarines and in aircraft for various structures.

    - A material I have found useful in bonding of many plastics is Lord 7542. It is a 2-part urethane that cures in about 1-2 hours. Bonds to many plastics including FRP very well.

    - If you get into bonding rubber piping or PTFE piping, we have methods here that may be useful for you.

    - I'm sure you recall that sailors will do chin-ups on anything they can jump up and grab. Keep that in mind when you design joints and hanger spacings. (I heard a mournful story of sailors doing chin-ups on the radar waveguides for an AEGIS phased array VLS weapons control system.)

- Adhesive selections

    - The Lord 310, 320, and Armstrong A12 all give different properties depending on mix ratio. I have tested them at different mix ratios to compare results. The Lord 310, in my experience, has excellent properties but runs on the brittle side. It has fairly low elongation to break. I consider that a negative for shipboard use where sharp blows are common. Since you are dealing with virtual non-structural applications, I would defer to toughness rather than strength. The A12 has widely varying temperature resistance depending on mix ratios. Watch this for fire safety.

    - The advantage to acrylics is they will cure better at colder temperatures than will many epoxies. They can also be brittle so some care is needed there.

- The adhesives you've screened may also be useful for joining the pipes. It would be useful to look at their bonding in those applications as well. As mentioned, I would include the Lord 7542 in that type of evaluation.

- I agree in your elimination of cyanoacrylates and anaerobics from the round robin testing. They are sensitive to surface conditions and bond gapping where the epoxies, acrylics, and urethanes are less so. Cyanoacrylates have relatively low temperature performance which could be a problem in fires as could outgassing. The anaerobics will *not* cure in the presence of air and exclusion of air in a bondline can be a real problem in repair. Cures can be brittle. All in all, it's a good call.

- I like to consider mix ratio and component viscosities as a handling issue. I prefer low mix ratios, in the 1-4:1 range. I also like to see both components have similar viscosities. Ability to purchase the product in premeasured cartridge kits is handy, too. All of these physical issues make the adhesive into more of a tool rather than an adventure in mixing and mess. High mix ratios, like 10:1, mean it is easier to get the ratio off or to have bad mixing uniformity. This can lead to poor cures. A system with premeasured cartridges, disposable in line mixing tubes, and a cartridge gun strikes me as ideal. Unused material is not mixed and wasted. The mixer tube can be left to cure and thrown away.

All together it appears you have tried to include the important considerations in your selection criteria. Since the applications are not terribly demanding structurally, many of the adhesives you have reviewed will probably work. If you forward more of the data, I will review that and offer more concrete thoughts on which ones I like and for what reasons.

Sincerely,

George W. Ritter, PhD
Principal Research Engineer
Microjoining and Plastics

December 2, 1997

Albert W. Horsmon, Jr.
University of Michigan Transportation Research Institute
Marine Systems Division
2801 Baxter Road
Ann Arbor, MI 48109-2150

EWI Project No. 41961CSP, Review of Marine Bonding Tests

Dear Mr. Horsmon:

Thank you for the additional information you forwarded on your adhesives selection work. There are a few comments I have on the data and also some thoughts regarding the selection process.

It is not surprising the major structural failures in the bonded systems occur between the primer/paint layer and the steel. It greatly simplifies the adhesive selection process, although it limits the structural loading to the adhesion value of the primer/paint system. That usually runs about 1200-1500 psi in tension and is probably quite a bit lower in peel or shear.

The good news is you can use about any adhesive or adhesive system you want as long as it sticks to the paint. It also means you can choose adhesives based on ease of use and application without as much concern about absolute performance.

Another key feature was that most failures were due to reverse impact on the painted surface. That is a problem because it means backside impacts can knock bonded components off the front side (bonded side) of the structure. Unfortunately, there is little that can be done from an adhesive standpoint to help that. One option is to continue using tape adhesives or especially foam-cored adhesives which may help with reverse impact resistance.

TAPE and FOAM SYSTEMS

The cited tape system, 3M 4941, is an acrylic adhesive with a nominal temperature resistance of 300^{o}F. Others you might consider include 3M 4965, which has a neoprene foam core and a stated temperature resistance of about 380^{o}F. Avery-Dennison offers Avery 1185, with a short term temperature resistance of 500^{o}F. It is also an acrylic adhesive. There are two silicone-based tape systems from Adhesives Research which both offer temperature resistance to 500^{o}F. These are AR 8458 and AR 7163. The higher temperature resistance may offer a marginal improvement in performance during fires, especially in fringe areas.

With any tape or foam system, a heavier load of adhesive, perhaps 3-5 mils, will help with wetout on a rough surface. Painted surfaces often have fairly heavy surface orange peel which hampers the ability of the adhesive to wet the surface. It is useful to heat the surface moderately with a hot gun prior to application of a pressure sensitive adhesive (PSA). This will also improve wetout quite a bit. For any PSA, surfaces must be clean, dust-free, and dry before application of the tape system. A simple surface preparation might be sanding and a solvent wipe to remove roughness and dust.

The importance of humidity testing for any bonding system can not be overemphasized. Your final testing criteria might consist of one-month hot/wet exposure (140°F/saturated humidity) bonded to the painted steel. This would hold true for both tape/foam or paste systems.

PASTE SYSTEMS

The major drawback to using paste (liquid) adhesive systems is their curing time. They have the advantage over tape/foam systems because of their wetting and tolerance to surface irregularities or modest dirt. They can be supplied in premeasured dispenser systems easily for use in original assembly or repair. Because the breadth of selections is so great, I keyed on fire retardance as a possible contribution to the overall selection effort. For example, 3M manufactures DP100 FR which is similar to the 3M system you have tried. That carries UL-94VO and also FAA-14CFR25.833 fire retardance ratings. I noticed the Norcast FR 7316 in the earlier list. I am assuming the “FR” means fire retardant.

The issue of fire retardance can be carried a bit far. Since you are bonding to the primer/paint, back-side heating of an area could easily cause the paint to fail and the bonded component to fall off. If the paint is intumescent, it may blow the component off the surface when it foams.

You are probably aware that you can’t have both fire retardance and smoke abatement. If there is flame retardance, there is usually increased smoke generation and vice versa. This is simply because lower burn temperatures produce more smoke while higher burn temperatures incinerate the smoke at the expense of more CO_2 generation. The lower burn temperatures also result in increased CO and hydrocarbon production.

Even so, there are two major techniques for making an adhesive more fire retardant: chemical additions and glass microsphere additions. For chemical additions, brominated resins are used or brominated phosphorous compounds are used. The cheapest additive is alumina trihydrate which gives off water when the temperature goes above about 500°F. Chemical additive methods improve flame retardance but increase the potential for smoke.

Inclusion of glass microspheres improves fire retardance. Microspheres produce a “syntactic foam” adhesive which will have reduced shear strength and tensile strength. That doesn’t concern me much because of the bonding to paint which will still be the limiting performance layer. The heat release rate presumably is improved because the foam has less polymer per unit volume. The microspheres reduce the fuel value of the adhesive.

I haven't ferreted out specific adhesive types but companies producing syntactic adhesives include 3M, Ciba-Geigy, Lord, and Magnolia Plastics. You could pursue this with the vendors you already know through the program. You could also discuss the fire retardant properties and whether or not the improvement is significant.

RELEVANCE of FLAMMABILITY ISSUES

My assumption is the issue of fire retardance is a concern for overall fire safety. In fact, my major concern is mechanical stability rather than fire performance. The issue for adhesive performance in a fire may has less to do with absolute nonflammability and more to do with glass transition temperature, T_g. Most room-temperature curing adhesives have a T_g of about 70-90^{o}C or about 190^{o}F maximum. Above the T_g, the adhesive becomes completely plastic. It will move in any direction it's pushed without resistance. Most adhesives will lose all significant strength once the temperature exceeds the T_g by about 20^{o}F. Effectively that means the adhesive will let go mechanically very early in the progress of a fire.

Given the chances the adhesive will fail before it burns, you can allow for this by joint design. Designing hangers and other joints so they will fail in compression allows the joint to have a mechanical failsafe that prevents things from crashing down when the adhesive fails. After that, the only concern would be the fuel value of the adhesive which is negligible compared to whatever else is burning. Overall, rather than worry too much about the fire performance of the adhesive, I would assume it will fail and design accordingly.

A final thought regards curing of the adhesives. In the shipyard, and certainly at sea, curing temperatures may well be in the 30-40^{o}F range. This is another plus for tapes where you can heat the surface locally. For pastes, as you finish your down-selection, you may want to look at performance versus a cold cure. You can cure the joints in a refrigerator and then test them later.

I hope these additional thoughts are useful. Please call or e-mail if you have comments or want to discuss things more.

Sincerely,

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